QJets

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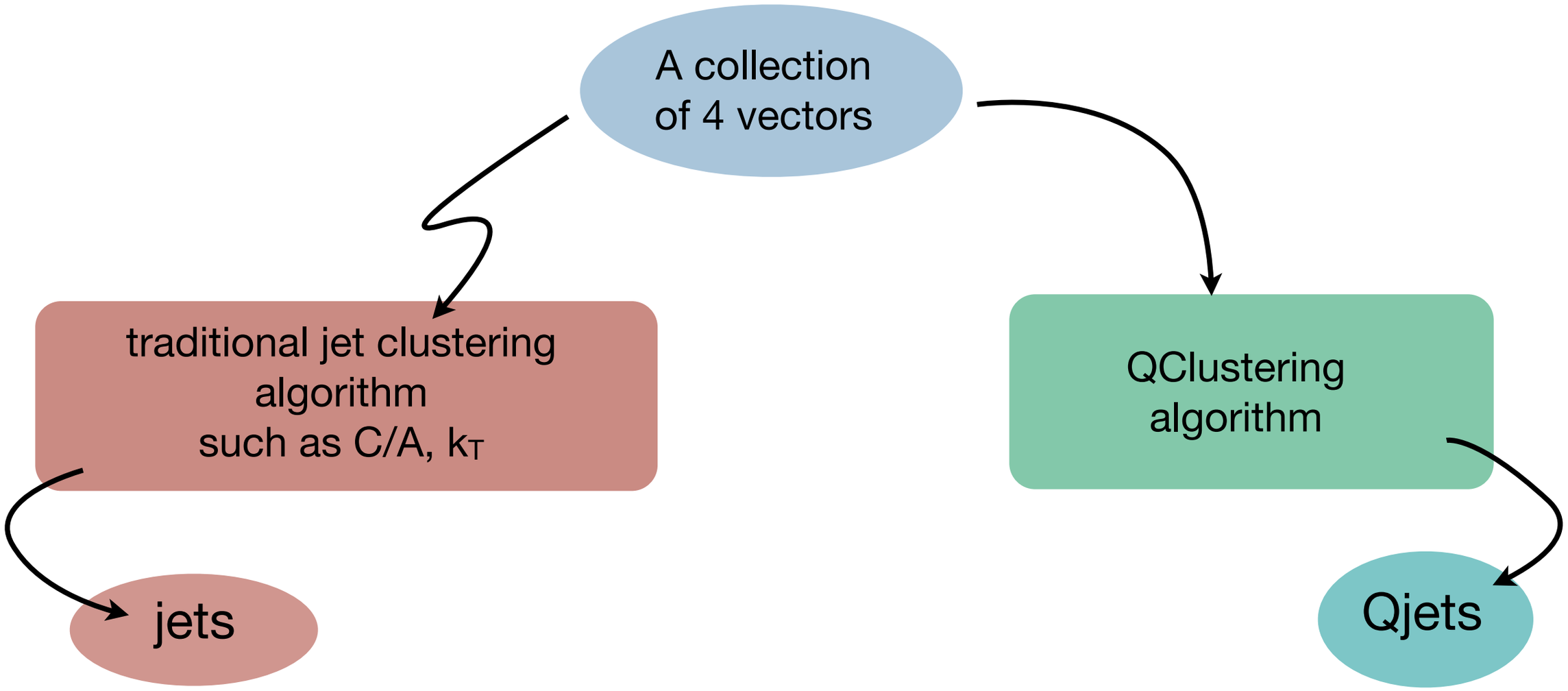
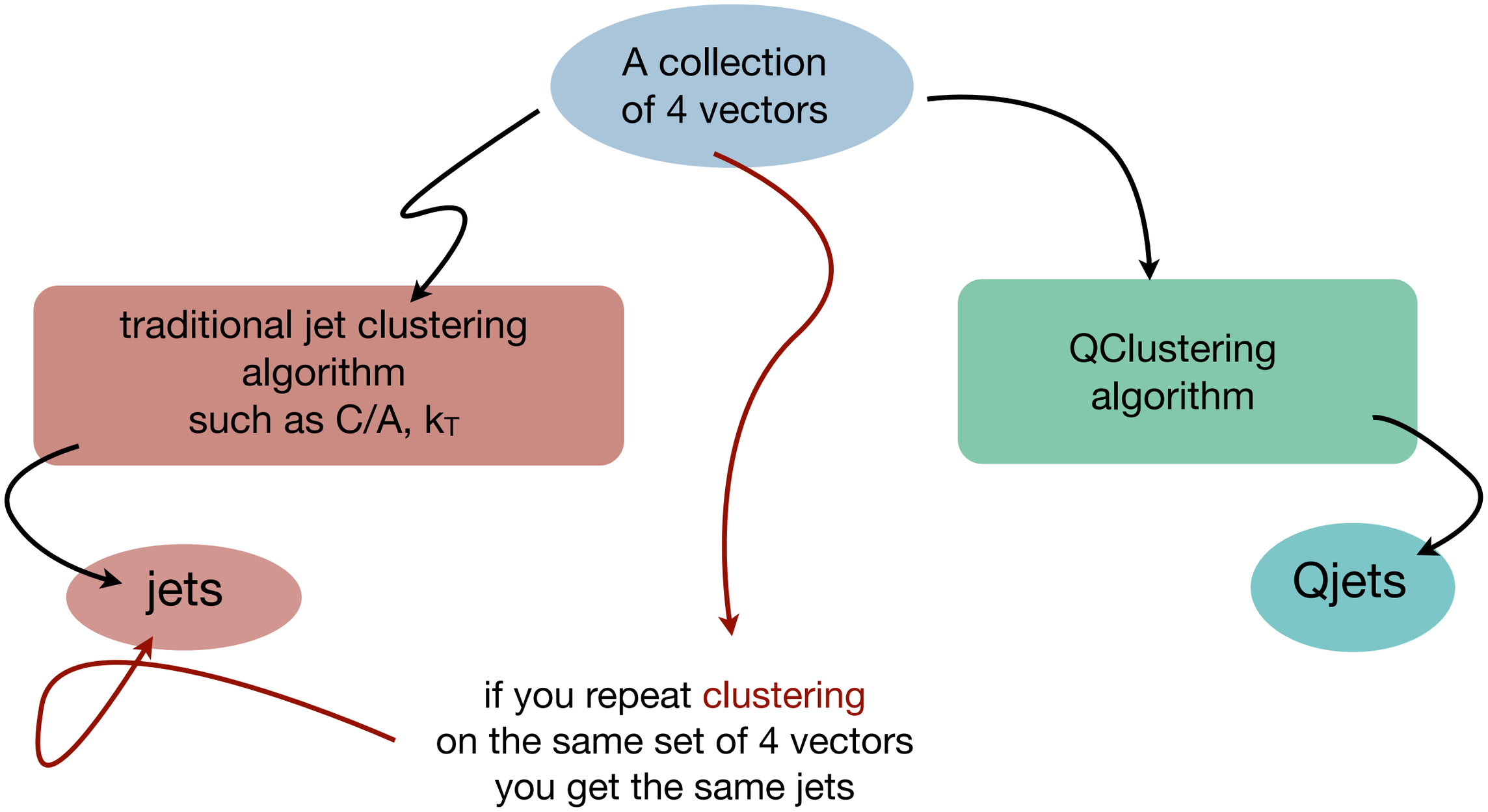
with Steve Ellis, Andrew Hornig, David Krohn
and Matt Schwartz

arXiv:1201.1914
work-in-progress

QJets


A collection
of 4 vectors
traditional jet clustering
algorithm
such as C/A, k_T
jets
QClustering
algorithm
Qjets

QJets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Qjets
if you repeat clustering
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you get the same jets

QJets

A collection of 4 vectors

traditional jet clustering algorithm such as C/A, k_T

jets

QClustering algorithm

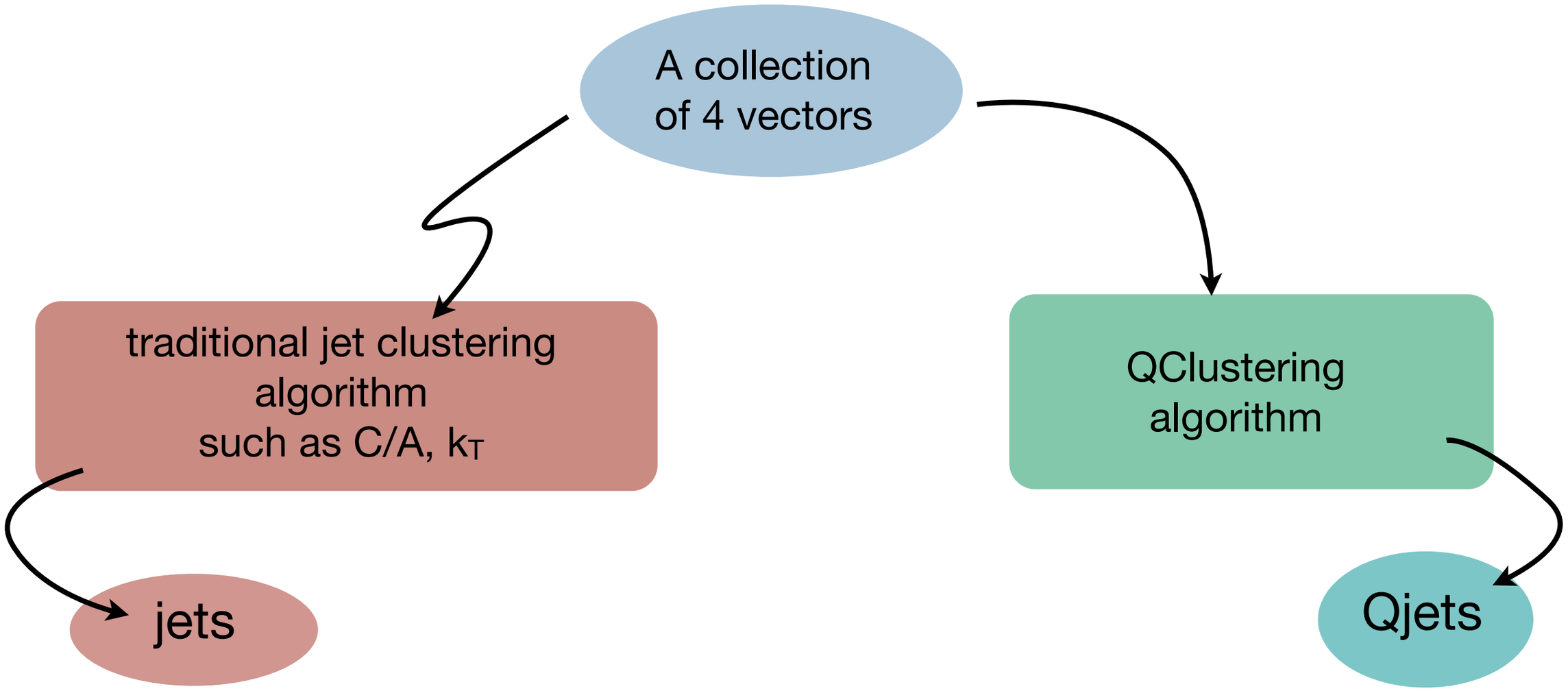
Qjets

if you repeat QClustering on the same set of 4 vectors you get different Qjets

Qjets

have different clustering histories

QJets



if an event is analyzed
multiple time using QClustering
a lot more information
can be extracted

QJets: why?

I will give a specific example:

- consider boosted and hadronically decaying W from WW events as a test case

- Use of Qjets significantly improves
  - discovery potential of W
  - measurement of W mass for a given luminosity
  - measurement of cross-section
  - determination of W four-vector

Outline

Boosted Jets and Substructure Analysis

- Applications in Higgs Search
- Pruning

Clustering vs QClustering

- QPruning
  - Applications

Boosted jets and substructure analysis

Butterworth, Davison, Rubin, Salam

0802.2470

Recipe for boosted resonance search:

(if you know what you are looking for)

- Look for “boosted” jets
- Identify “interesting” jets
- Clean jets

Boosted jets and substructure analysis

Recipe for boosted resonance search:

(if you know what you are looking for) ex. h -> bb

- Look for “boosted” jets

the angular separation of the decay products $\Delta R \sim 2\, m_h/p_{Th}$

“boosted jets” refer to jets containing four-vectors separated by $\Delta R \sim 1.0$ and with $p_T > 2\, m_h$

Boosted jets and substructure analysis

Recipe for boosted resonance search:

(if you know what you are looking for) ex. h -> bb

- Identify “interesting” jets

Higgs jets should have “mass-drop”

Higgs jets should be double b-tagged

Boosted jets and substructure analysis

Recipe for boosted resonance search:

(if you know what you are looking for) ex. h -> bb

- Clean jets
  - signal jets contain ISR + UE + pile-up other than the decay products
  - cleaning a jet involves guessing which components are not due to decay + FSR and getting rid of these
    - ex: filtering, pruning, trimming etc.

LHC Higgs reach

Butterworth, Davison, Rubin, Salam

0802.2470

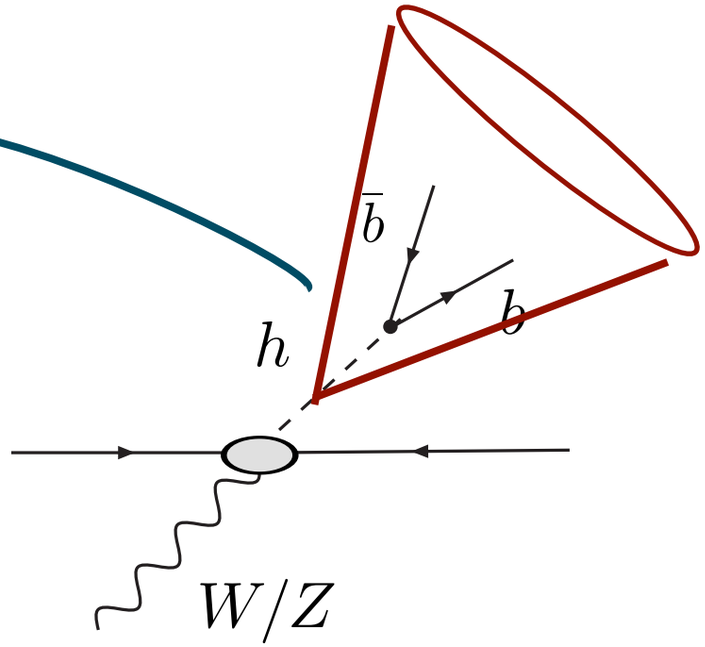
Ex. $pp \longrightarrow V\ h$

significance of 4.2 σ at $\mathcal{L} = 30\ \mathrm{fb}^{-1}$

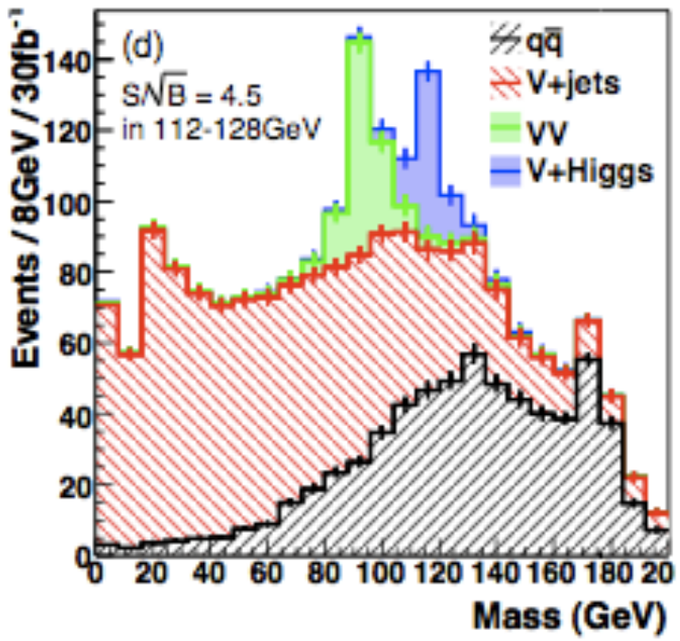
using jet-substructure for jets with $p_{T,h} > 200\ \mathrm{GeV}$

Jet with substructure

- subjets are significantly lighter than the jet
- splitting is not too asymmetric
- jet is double b-tagged



filtered

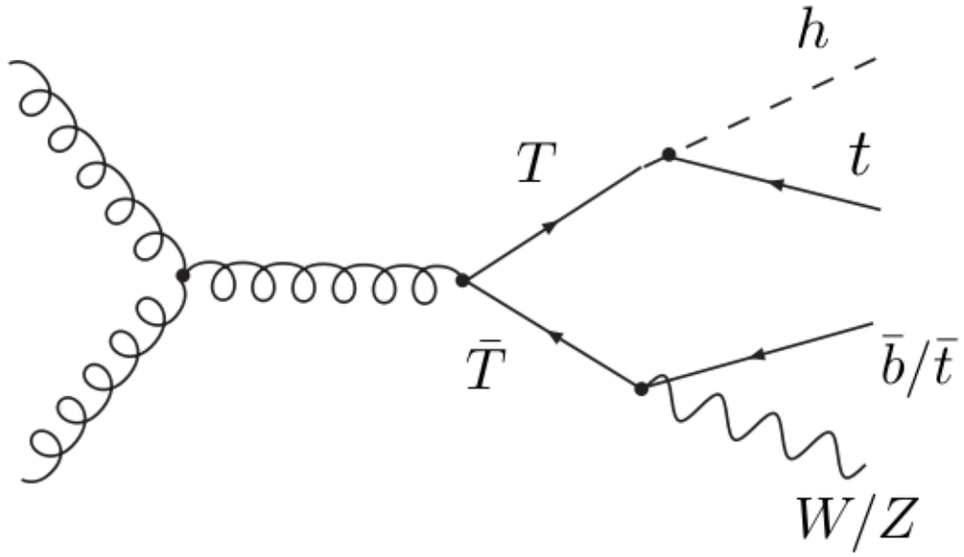


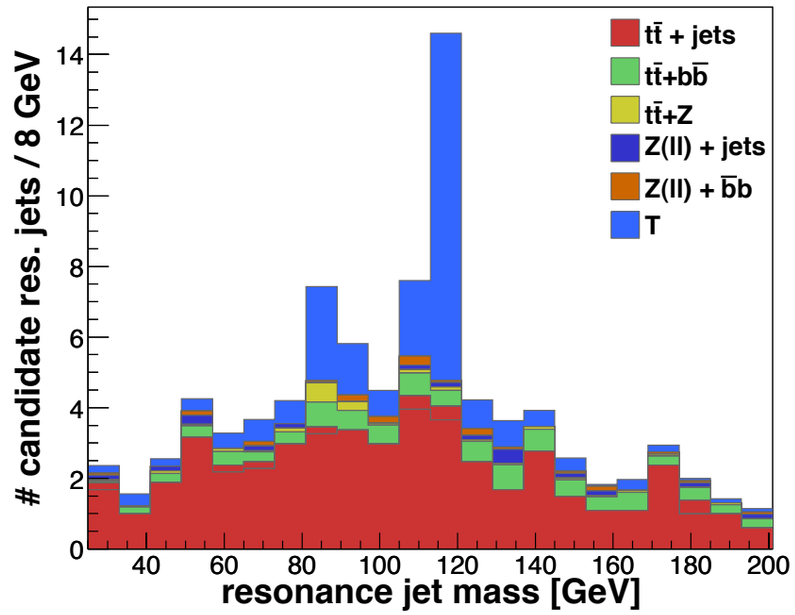
LHC Higgs reach

Kribs, Martin, TSR
1012.2866

Ex. Higgs from top partners

$$\sqrt{s} = 14 \text{ TeV}, \mathcal{L} = 10 \text{ fb}^{-1}$$





$$M_T = 800 \text{ GeV}$$

LHC Higgs reach

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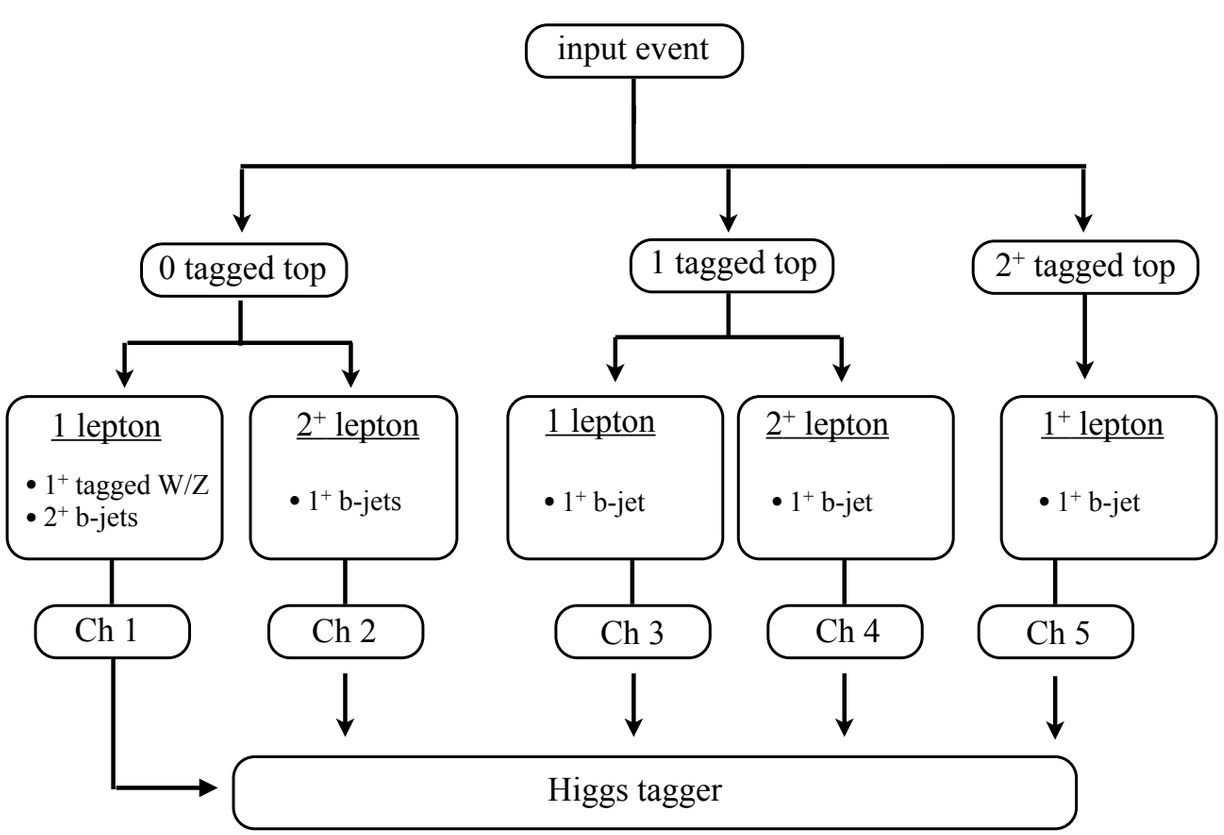
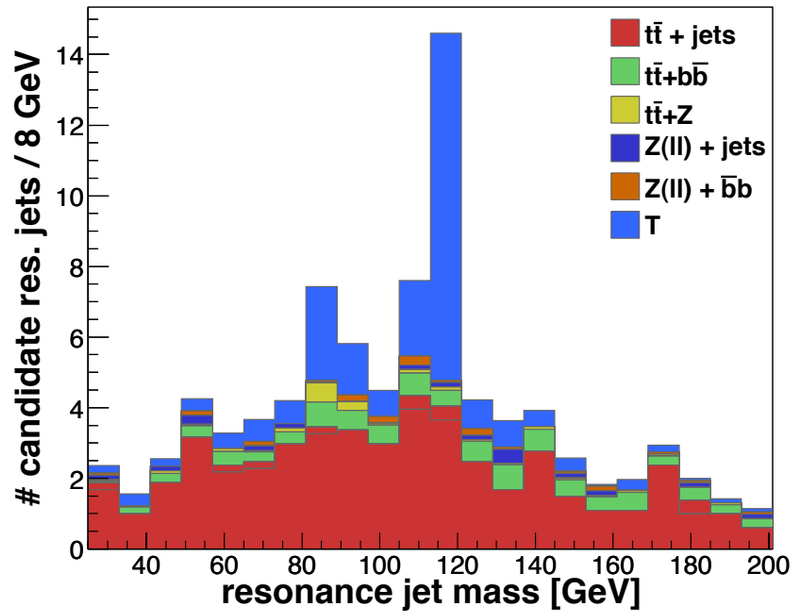




$$M_T = 800 \text{ GeV}$$

$$S/\sqrt{B} = 5.2$$

Boosted jets and substructure analysis

Recipe for boosted resonance search:

(if you don't know what you are looking for)

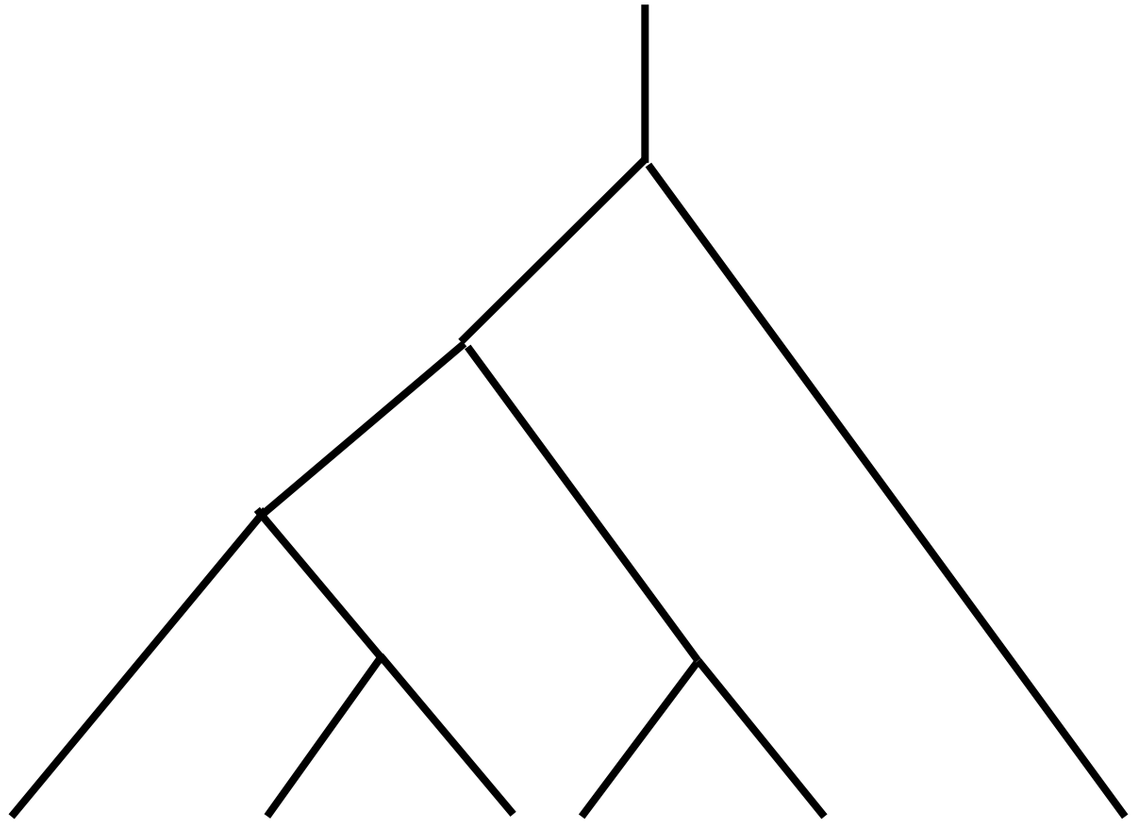
- Look for "boosted" jets
- ~~Identify "interesting" jets~~
- Clean jets

more important than ever

rest of the talk will be on how pruning can be made a more effective groomer.

Pruning

Start with the constituents of a given jet and rebuild the jet along C/A or k_T



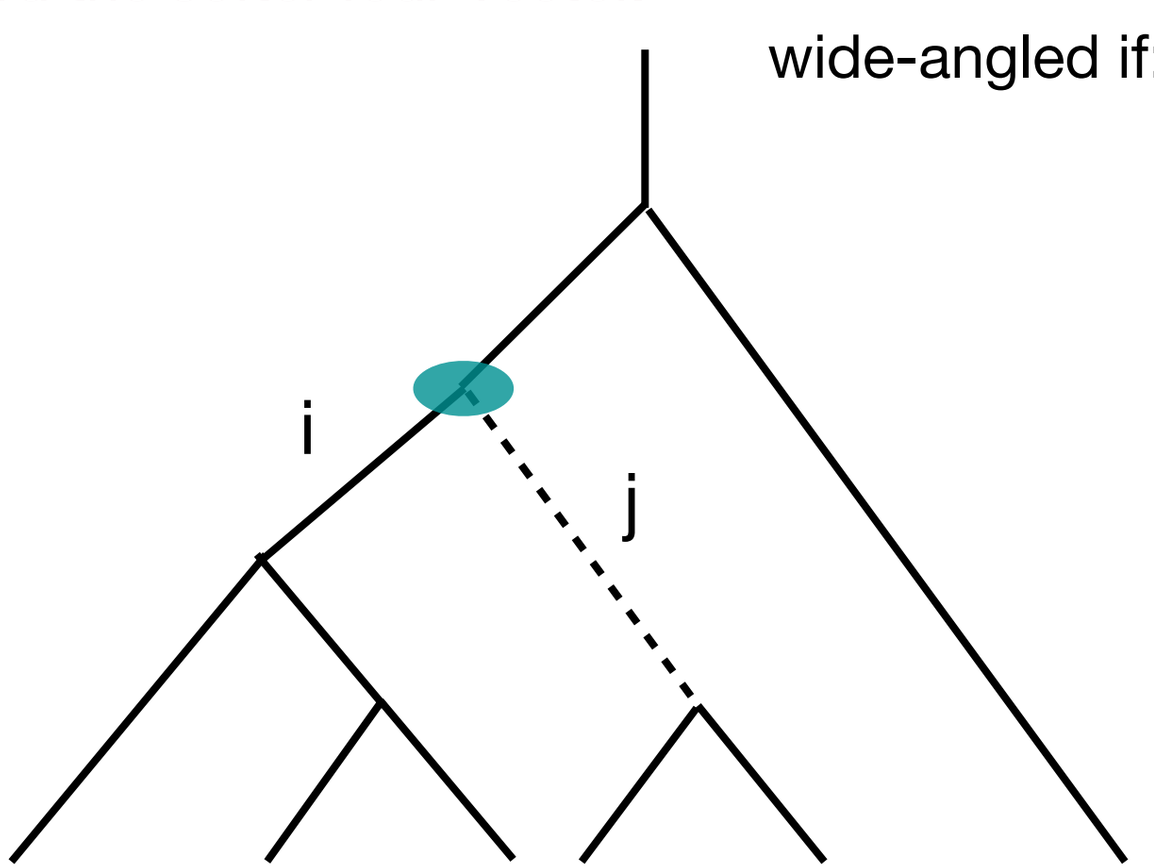
Pruning

At every step of clustering check whether the branch to be added is soft **and** wide angled.

- if yes discard the softer four-vector.

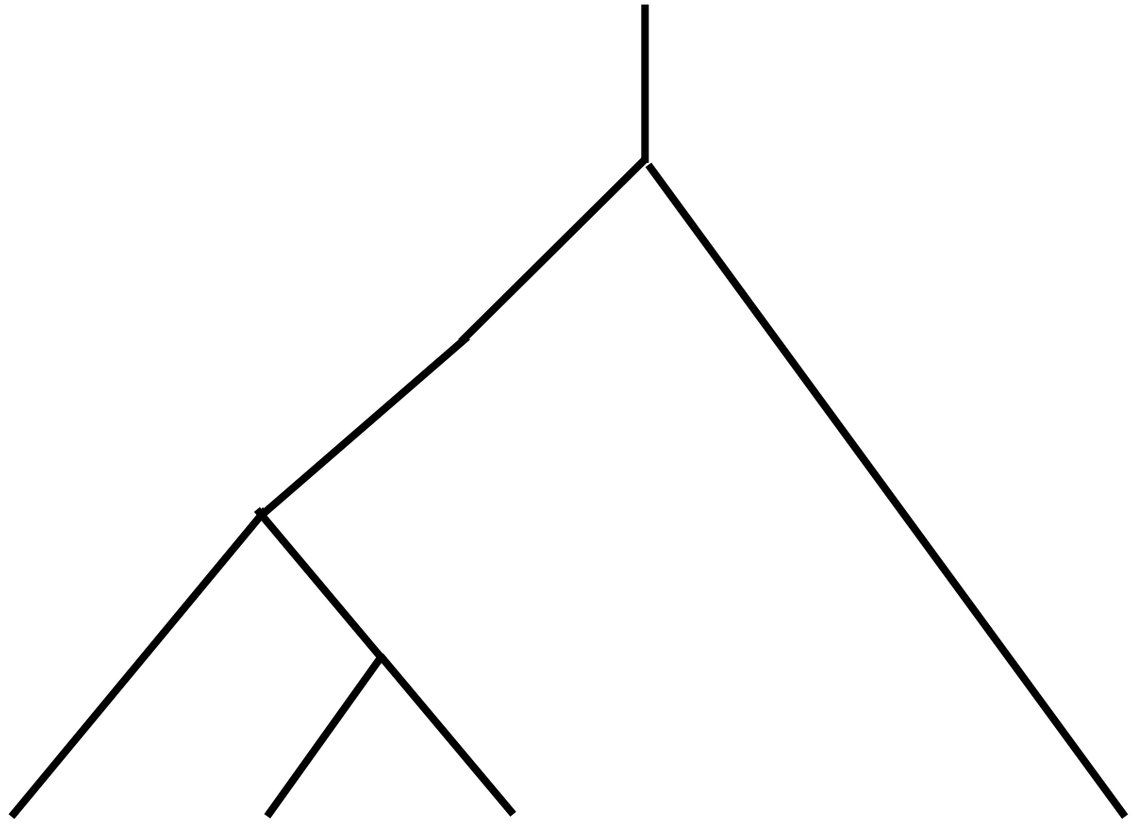
soft if: $\frac{\min\left(p_{T_i}, p_{T_j}\right)}{|\vec{p_{T_i}} + \vec{p_{T_j}}|} < z_{\text{cut}}$

wide-angled if: $\Delta R_{ij} > D_{\text{cut}}$



Pruning

Pruned Jet

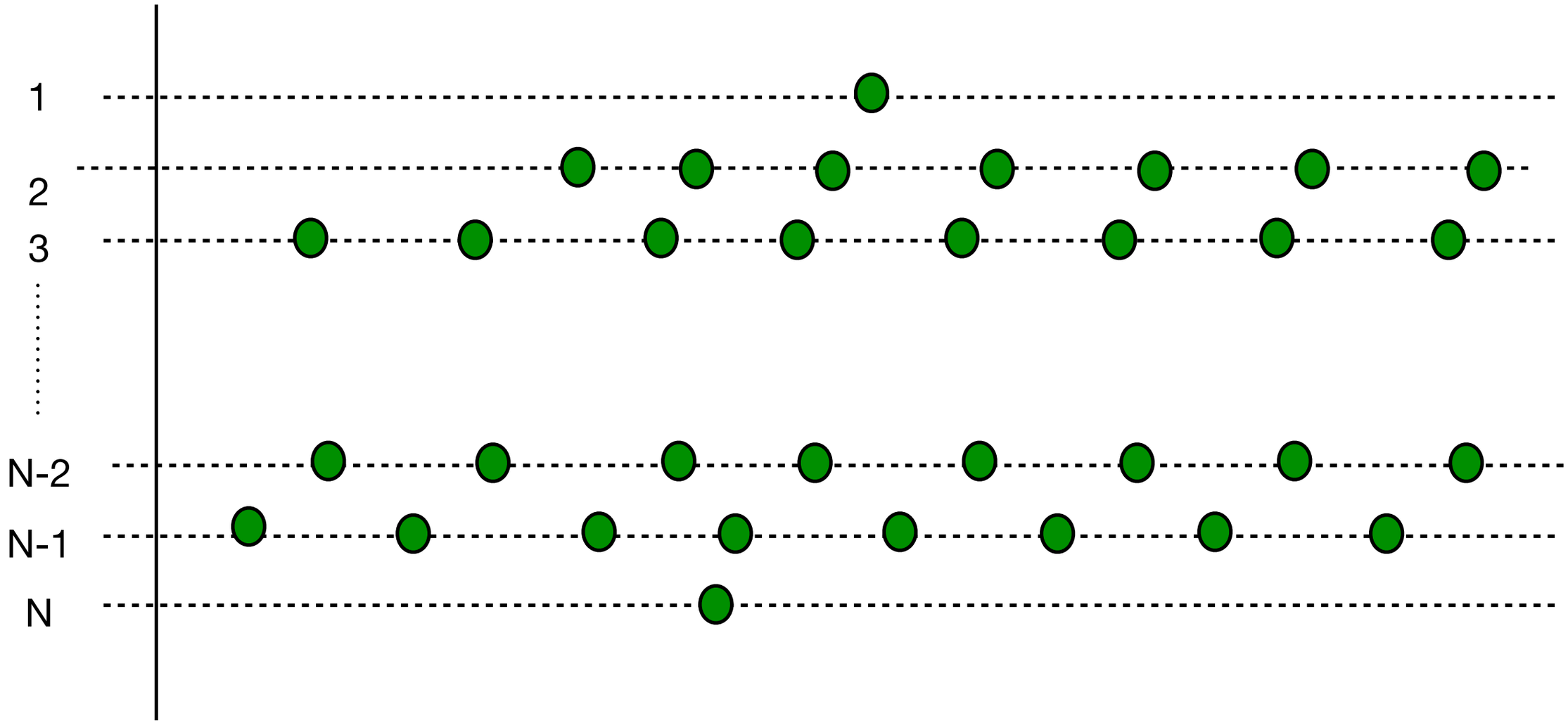


Pruning

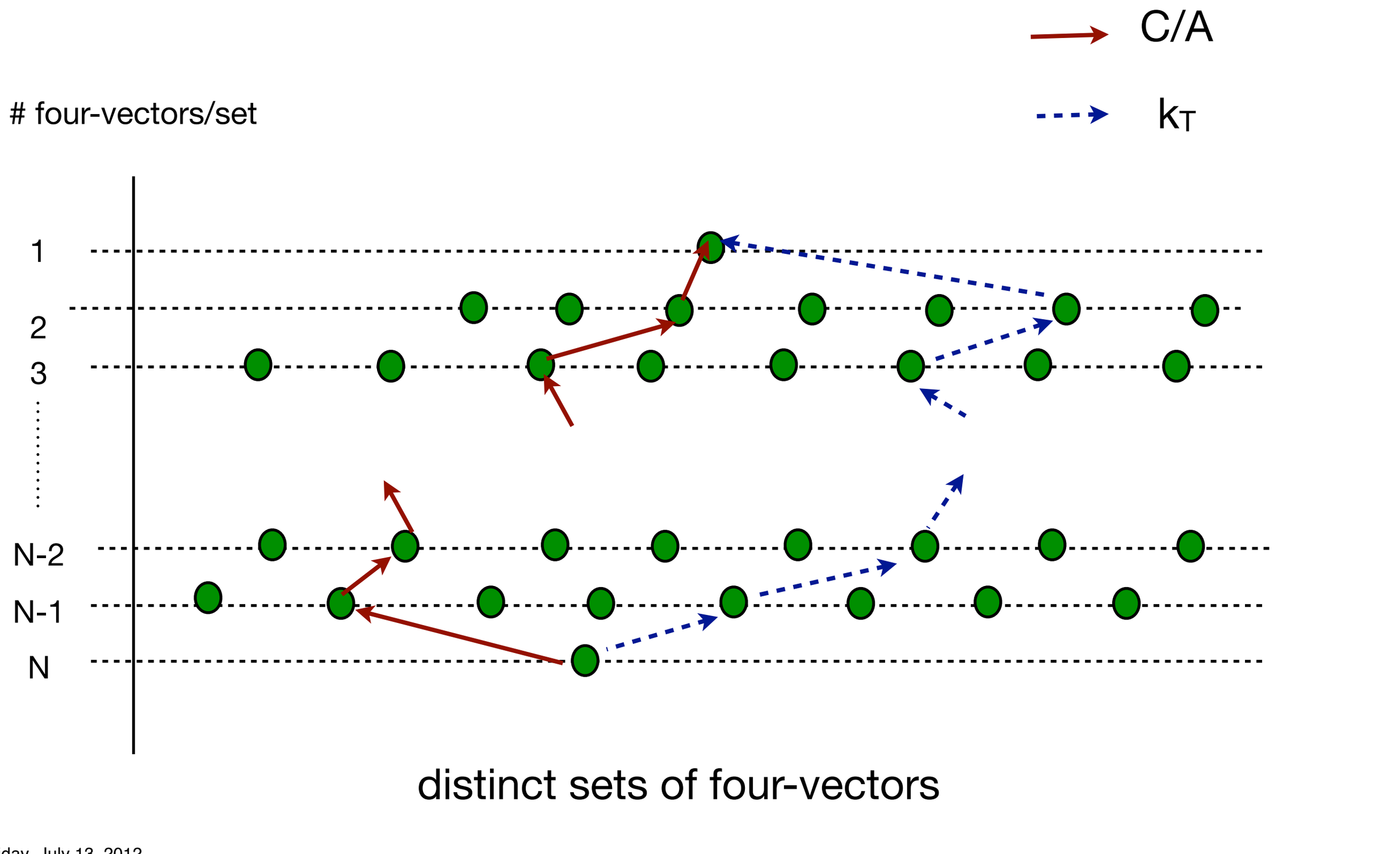
- Four-vectors that are pruned are actually branches of the tree.
- Pruned jets depend crucially on the tree-structure or the clustering algorithm used to construct the jet.

but who ordered the clustering algorithm?

Clustering

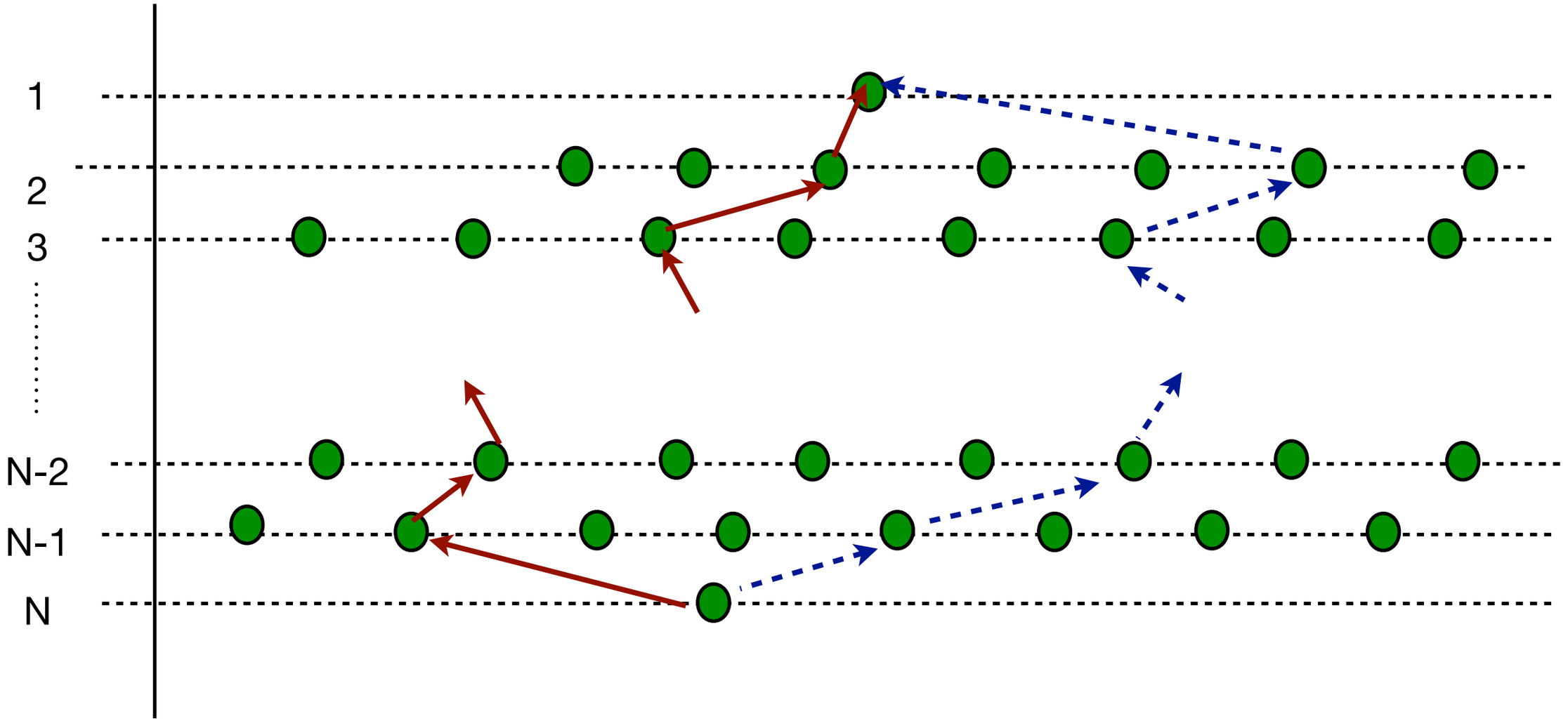


Clustering


C/A
k_T
four-vectors/set
1
2
3
N-2
N-1
N
distinct sets of four-vectors

Clustering

Many paths remain unexplored



distinct sets of four-vectors

Clustering

Many paths remain unexplored

A better formalism should explore all such paths

one needs to be clever since the total number of distinct trees is enormous

$$\frac{(2N)!}{2^N N!}$$

our prescription is QClustering

QClustering

As in a sequential recombination algorithm, assign every pair of four-vectors a distance measure d_{ij}.

However, unlike a normal sequential algorithm (where the pair with the smallest measure is clustered), here a given pair is randomly selected for merging with probability

$$\Omega_{ij} = \frac{1}{N} \exp\left(-\alpha \, \frac{d_{ij}}{d_{\min}}\right)$$

rigidity parameter

Repeat many (~100-1000) times, till the distribution stabilizes

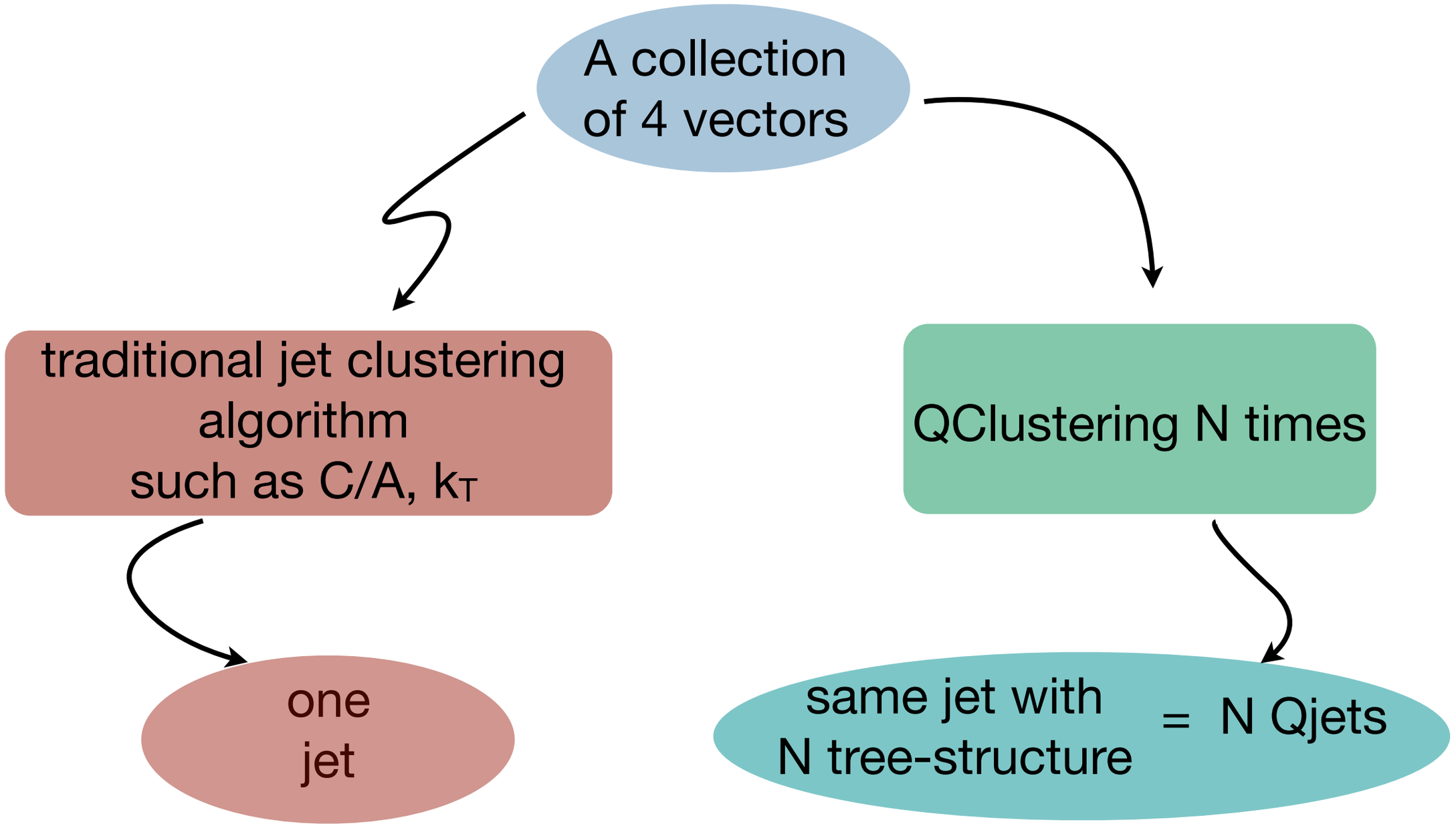
QClustering

$$\Omega_{ij} = \frac{1}{N} \exp\left(-\alpha \ \frac{d_{ij}}{d_{\min}}\right)$$

d_{ij} : we take C/A or kT measure

$\alpha \to \infty$	Classical regime: only path corresponding to d_{min} is selected
$\alpha > 0$	physical regime: physical paths are preferred
$\alpha \to 0$	democratic regime: all paths have same weight
$\alpha < 0$	unphysical regime: physical paths are de-weighted

QClustering vs. Clustering



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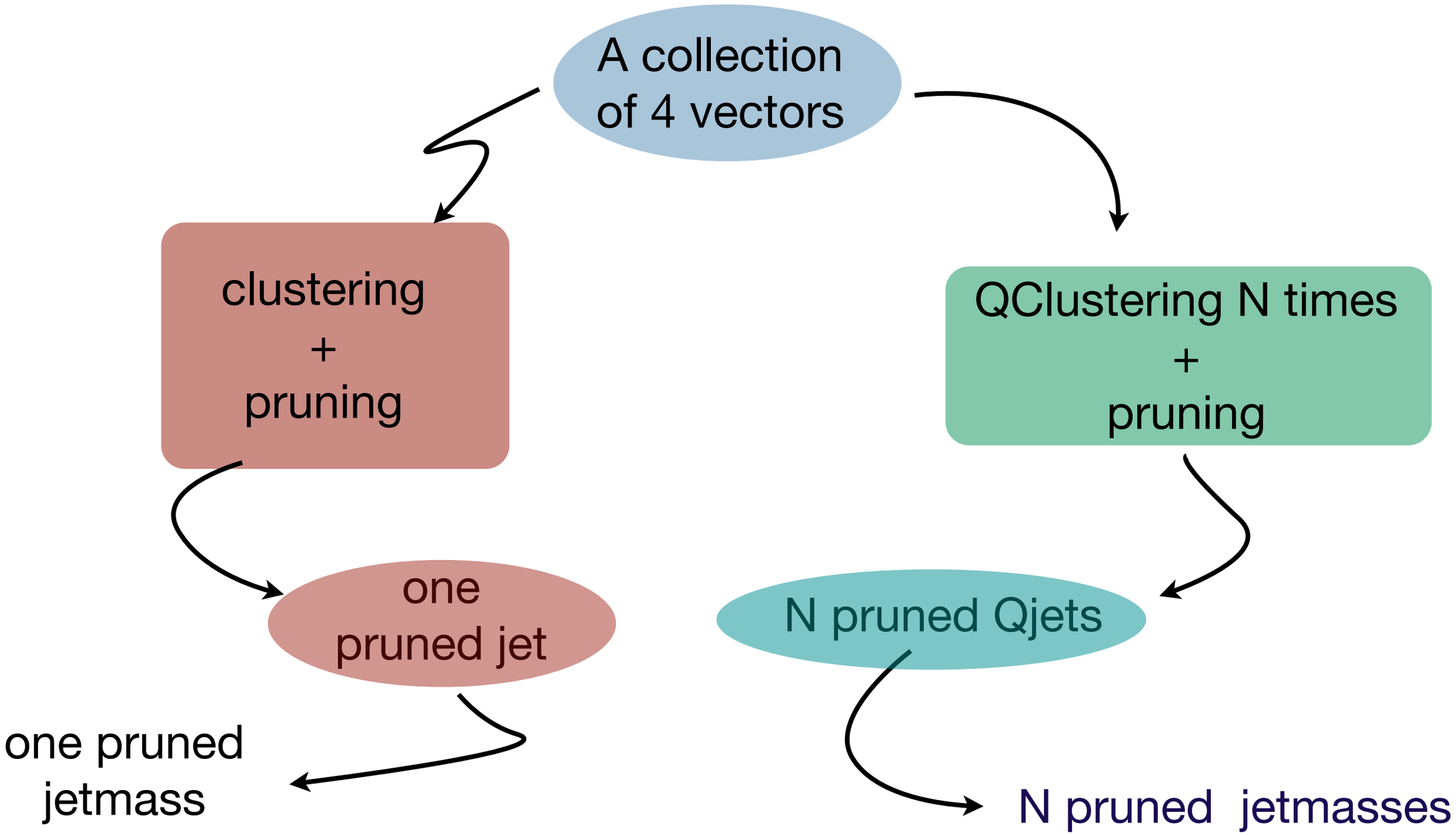

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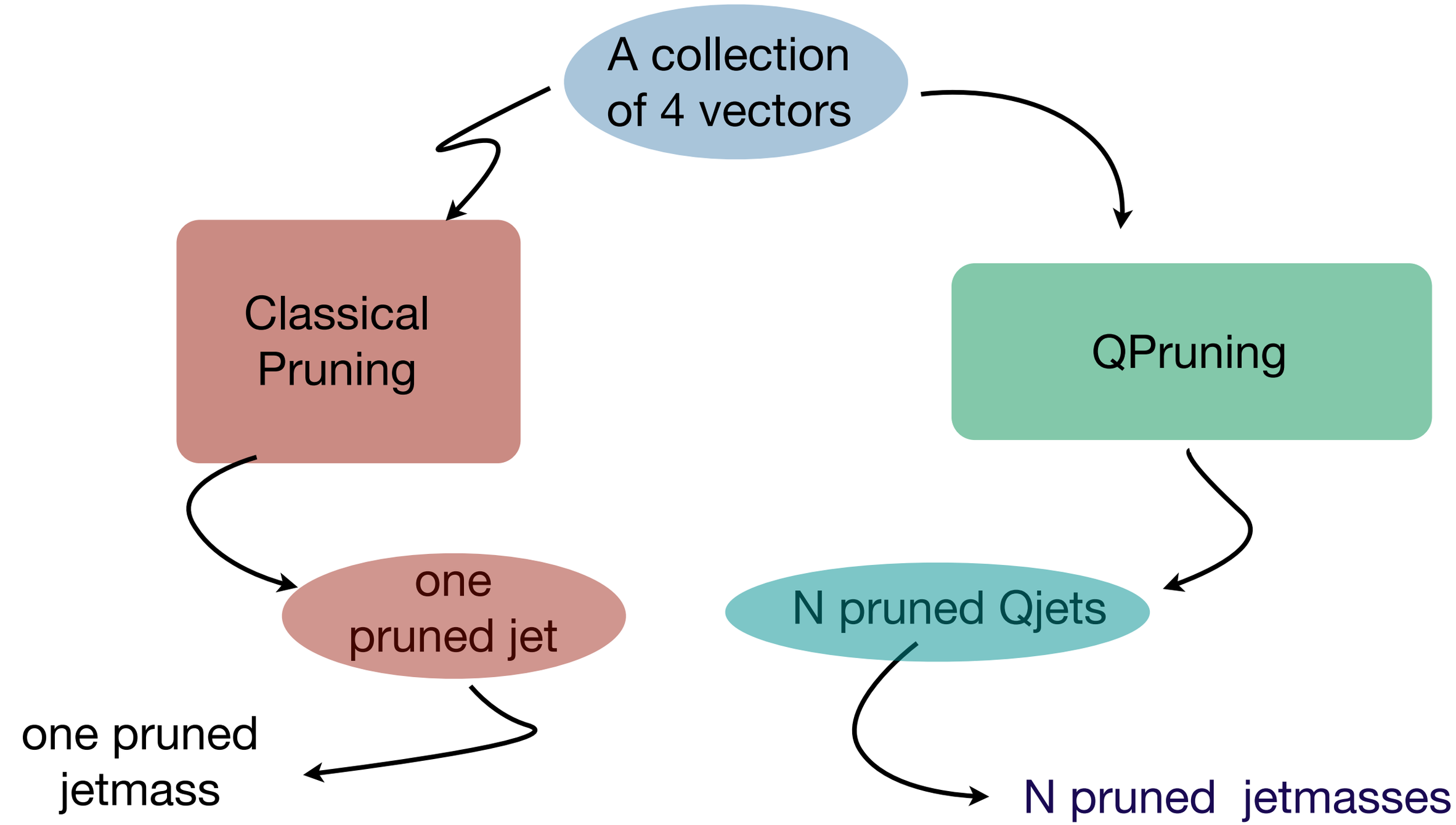
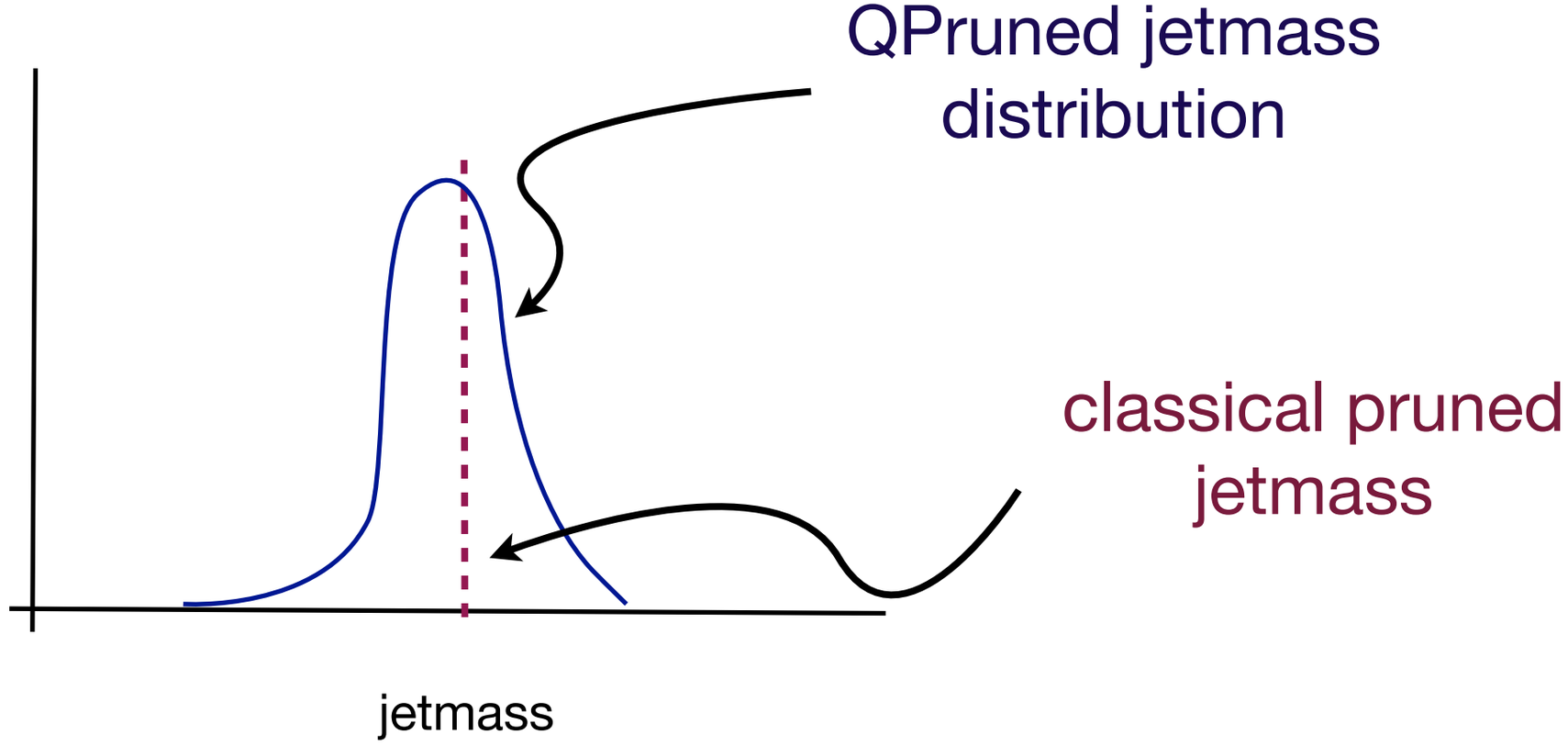


QClustering + Pruning

Ex. a hadronic W jet from WW events

The original jet is made from C/A algorithm with R = 1.0 and pT > 200GeV



QClustering + Pruning = QPruning

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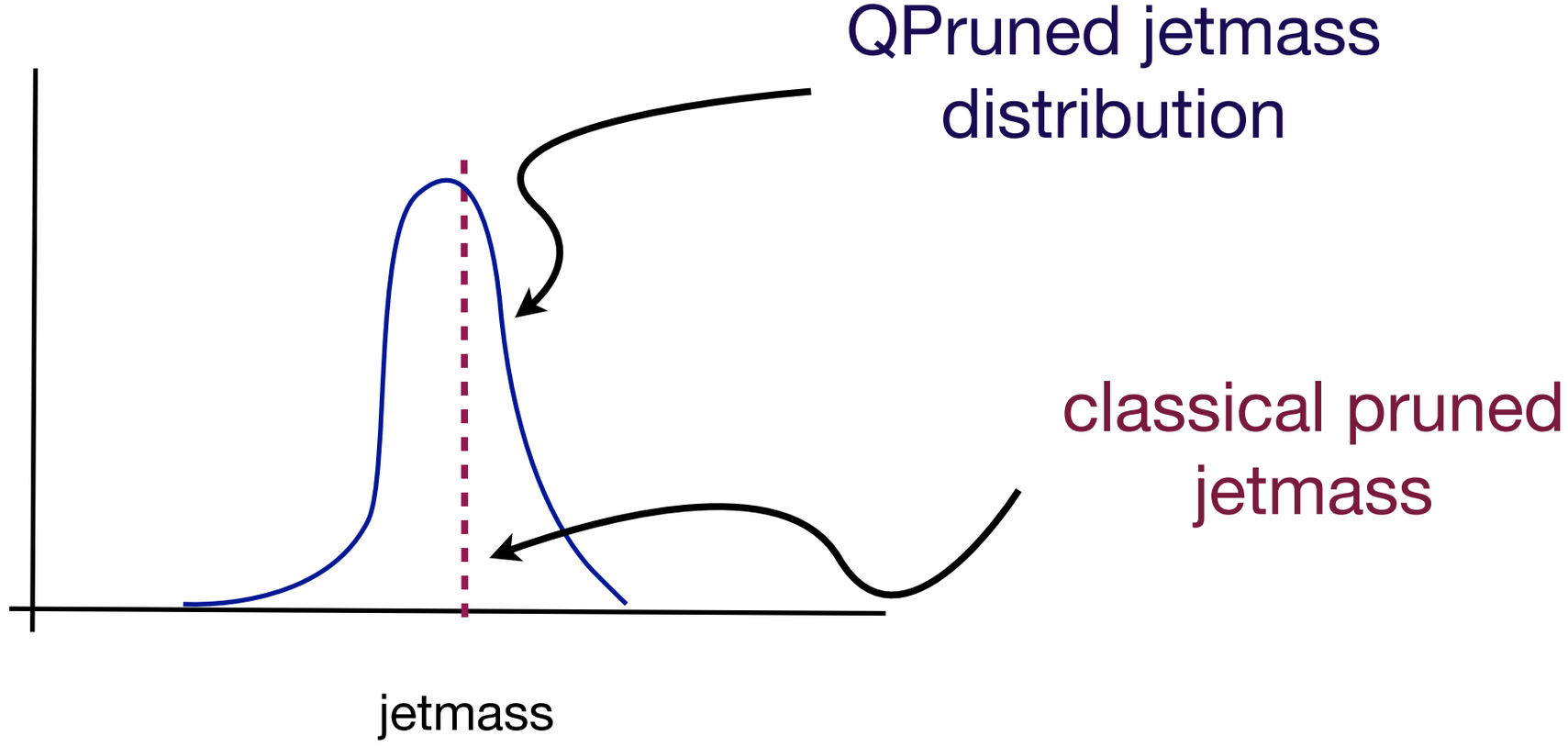

How can this distribution be used?

QClustering + Pruning = QPruning

Before we proceed, one comment about the choice of weight

$$\Omega_{ij} = \frac{1}{N} \exp\left(-\alpha \ \frac{d_{ij}}{d_{\min}}\right)$$

Who ordered the choice of d_{ij} and α ?

QPruning

Before we proceed, one comment about the choice of weight

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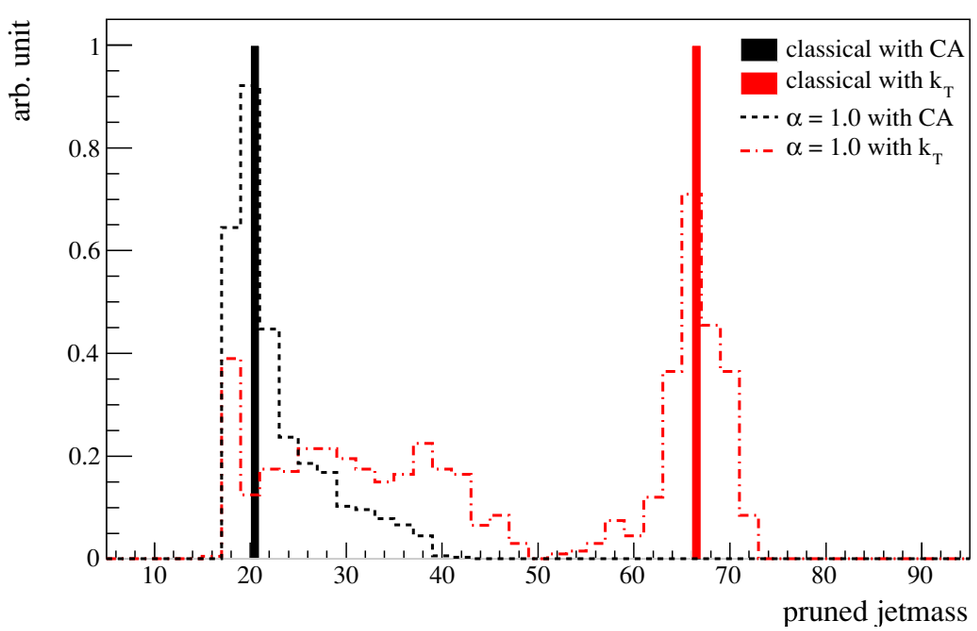
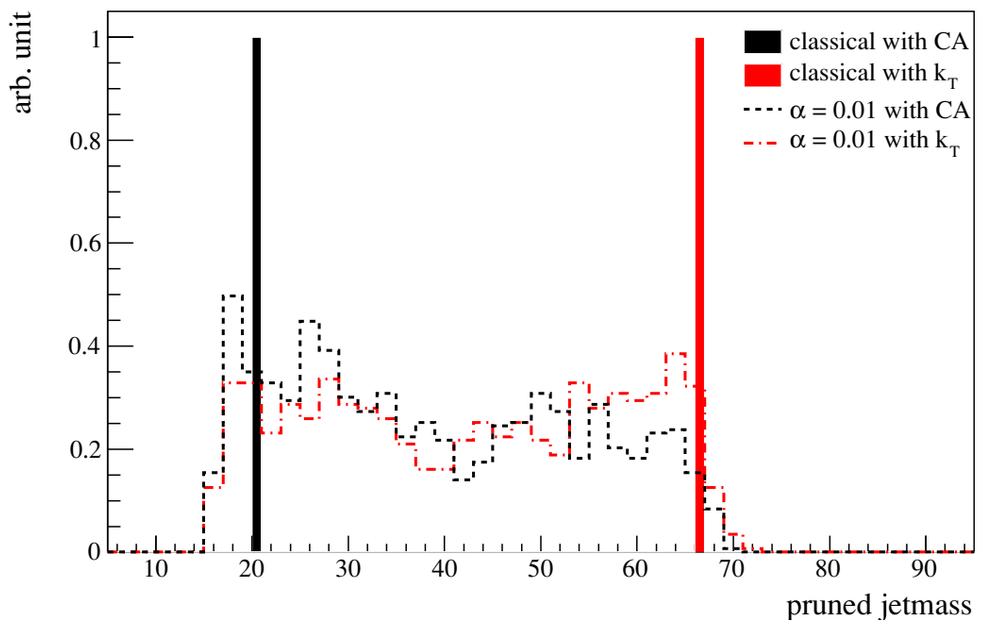




QPruning

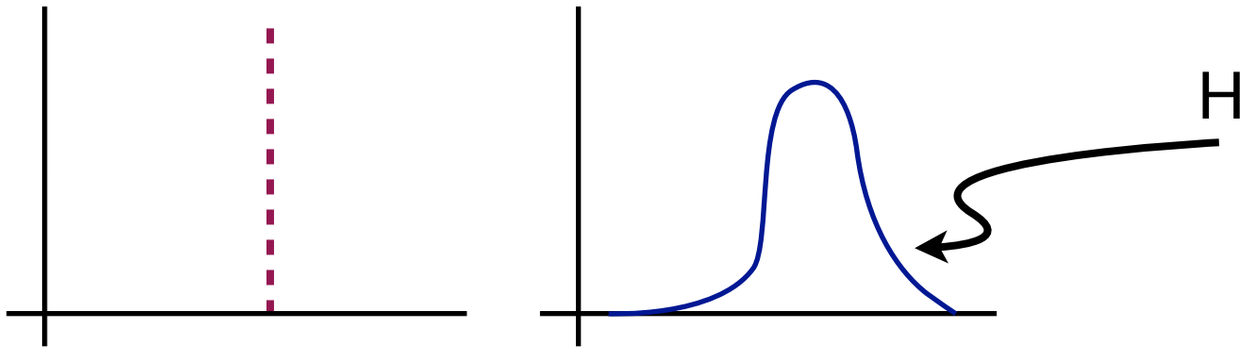
Before we proceed, one comment about the choice of weight

$$\Omega_{ij} = \frac{1}{N} \exp\left(-\alpha \ \frac{d_{ij}}{d_{\min}}\right)$$

For $0.1 > \alpha > 0$ our results are insensitive to the choice of α and the form of d_{ij}

QPruning vs. Pruning

Let us take a sample jet



Simply use the shape of the distribution to discriminate signal from background

Application in signal discovery

Use the distribution to reduce statistical fluctuations in measurements

Application in determination of cross-section, mass etc.

QPruning vs. Pruning

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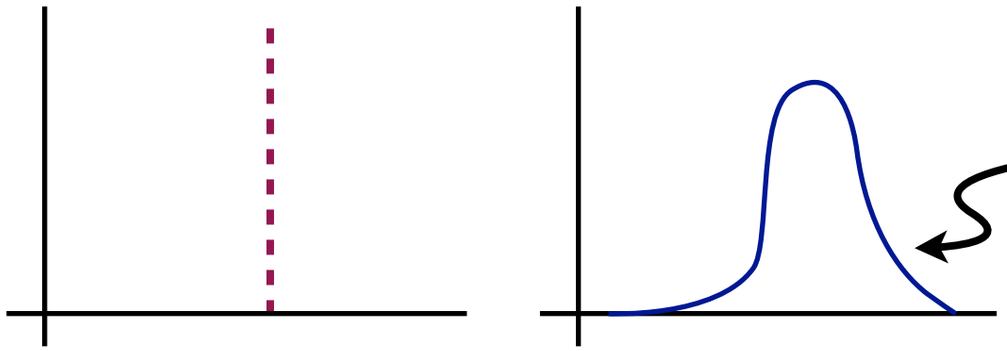

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classical pruned jetmass

QPruned jetmass distribution

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Application 1: discovery of W

- When there is an intrinsic mass scale for a jet, the pruned jetmass is more or less robust under variation of paths.

- Signal jets with decay products of massive resonances have intrinsic mass scales.

- Even QCD jets with $m/p_T \sim 1$ have hard splittings and hence intrinsic mass scales.

- But background is dominantly due to QCD jets with m/pt < 1/2 - whose masses are highly volatile.

Application 1: discovery of W

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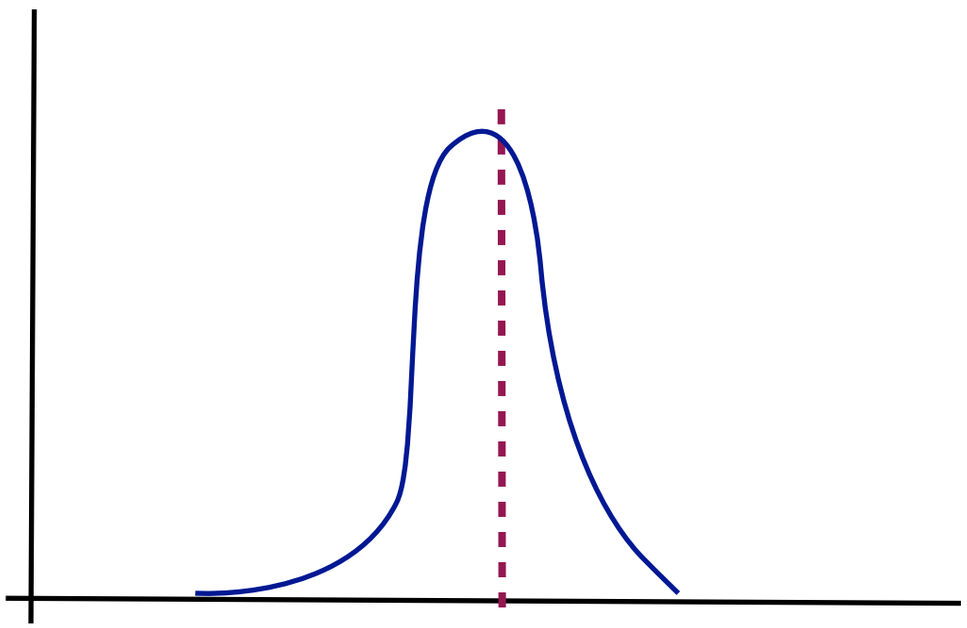
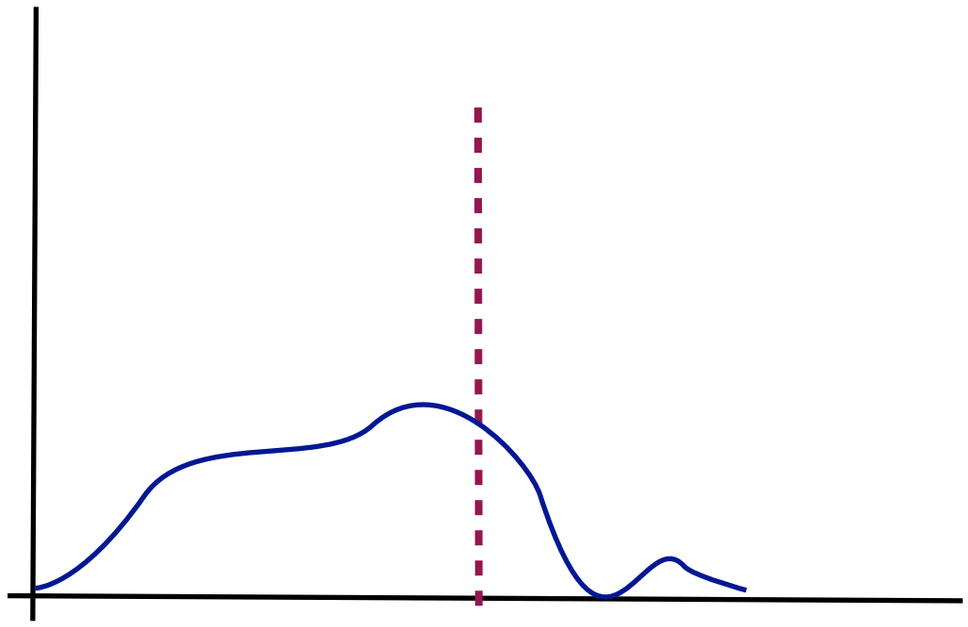
W jet



QCD jet with $m/p_T < 1/2$

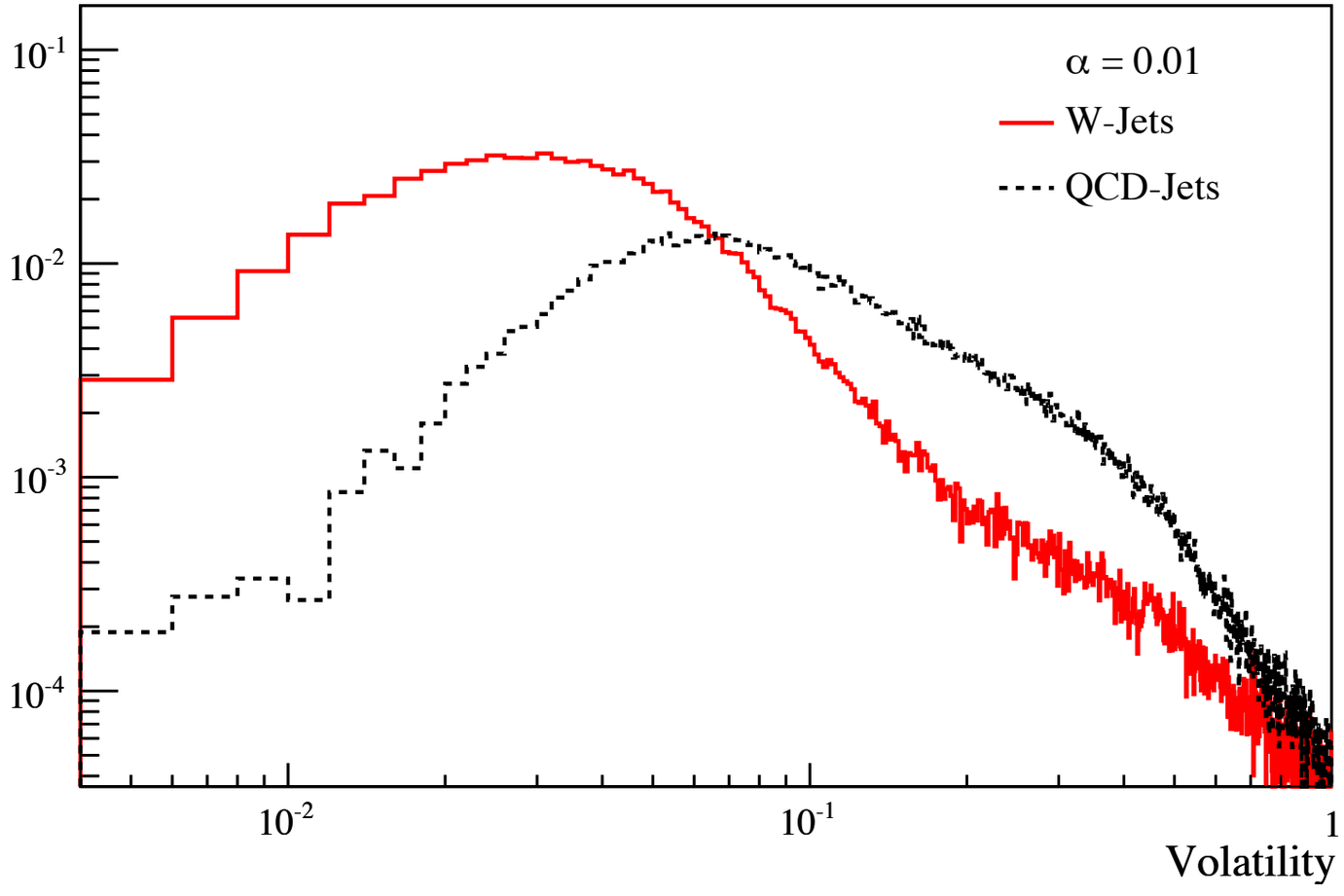


Application 1: discovery of W

volatility of a jet $\mathcal{V} = \dfrac{\omega_p}{m_p}$

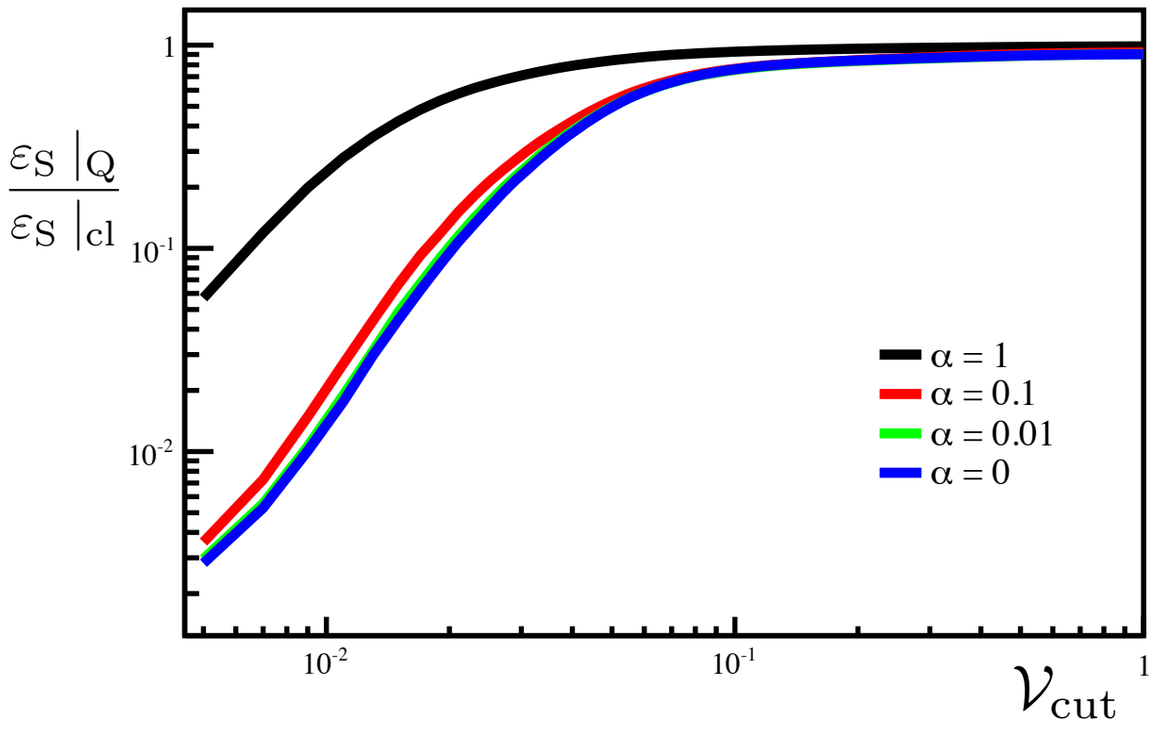
ω_p = width of jetmass distribution

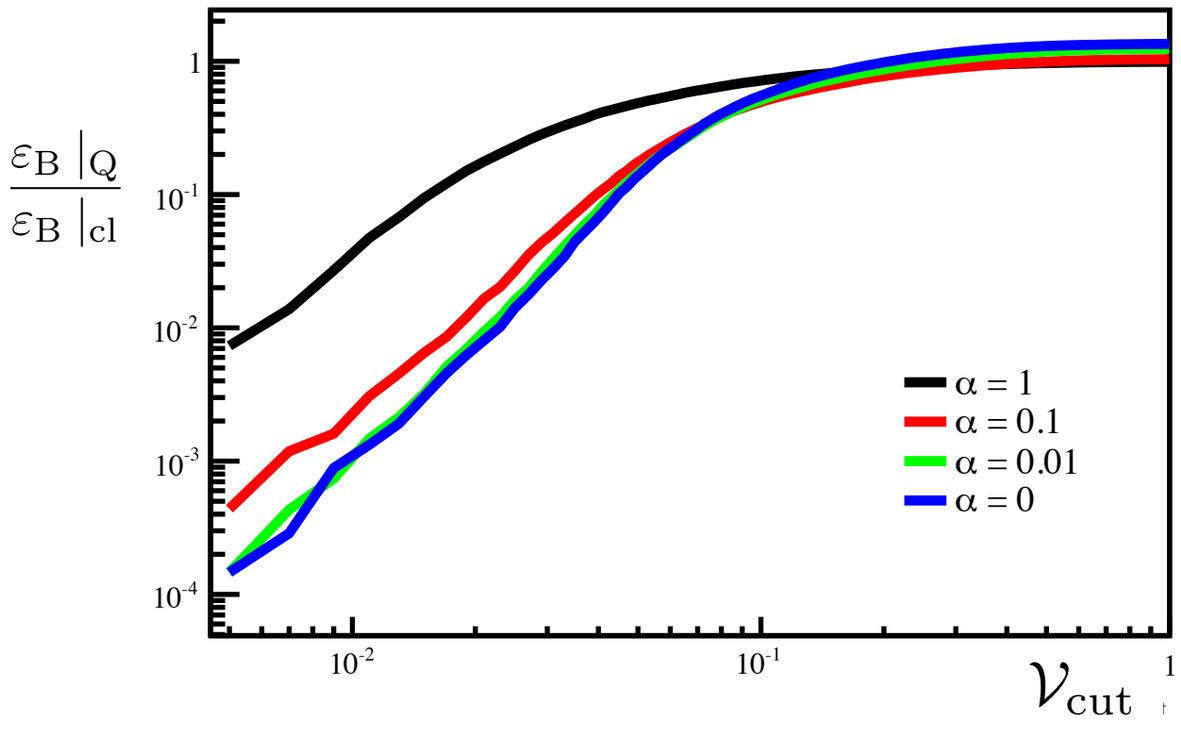
m_p = averaged pruned jetmass



Application 1: discovery of W

a cut on $\mathcal{V}$ decreases background significantly





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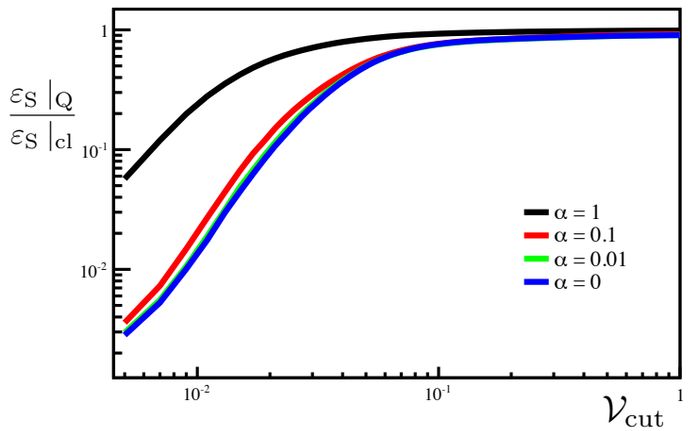
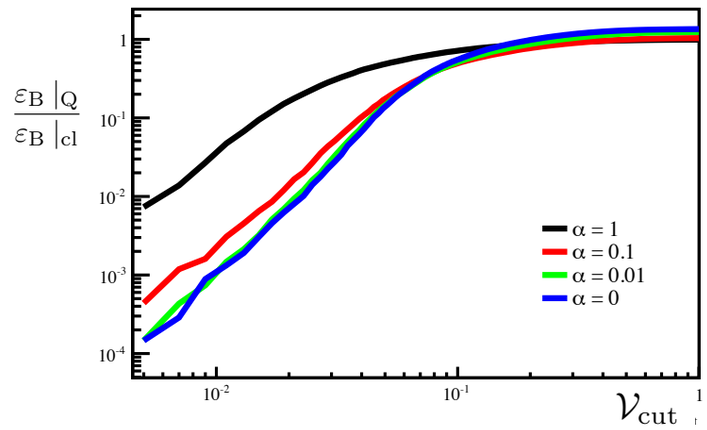
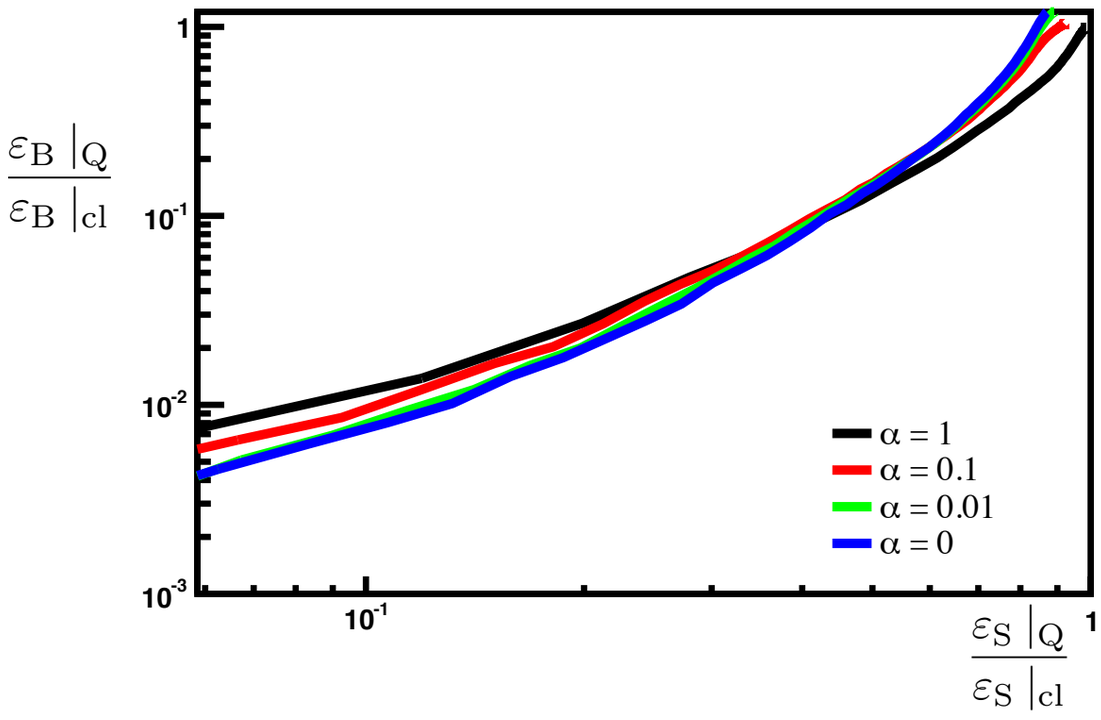
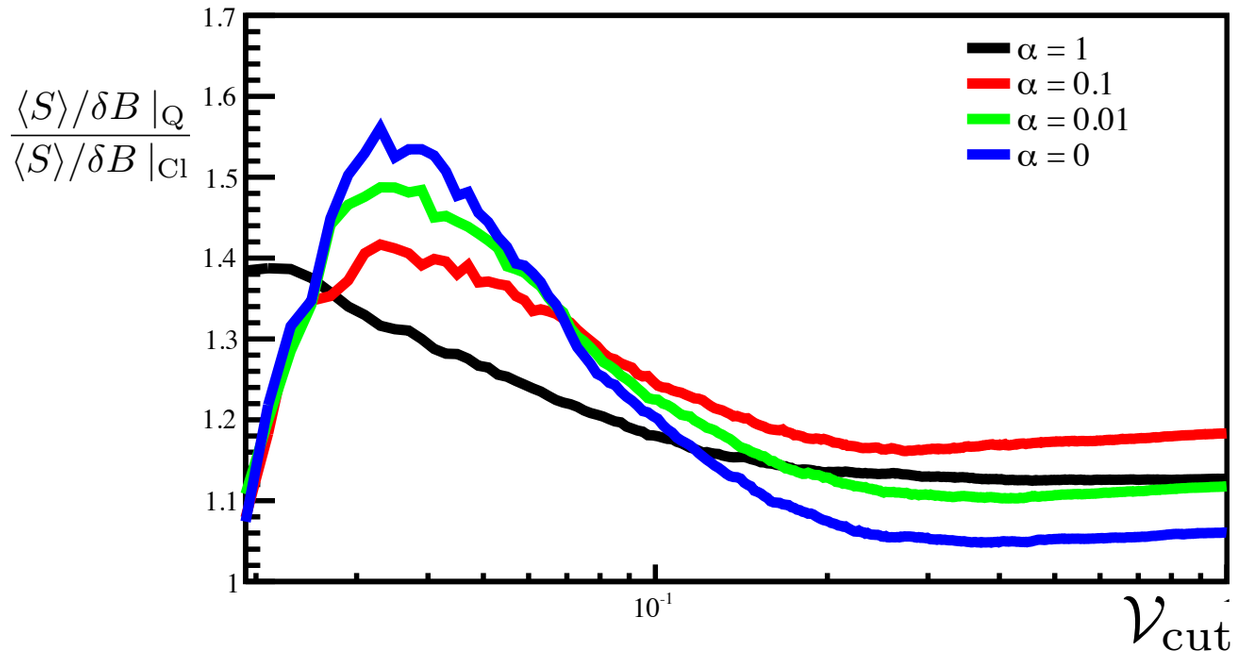




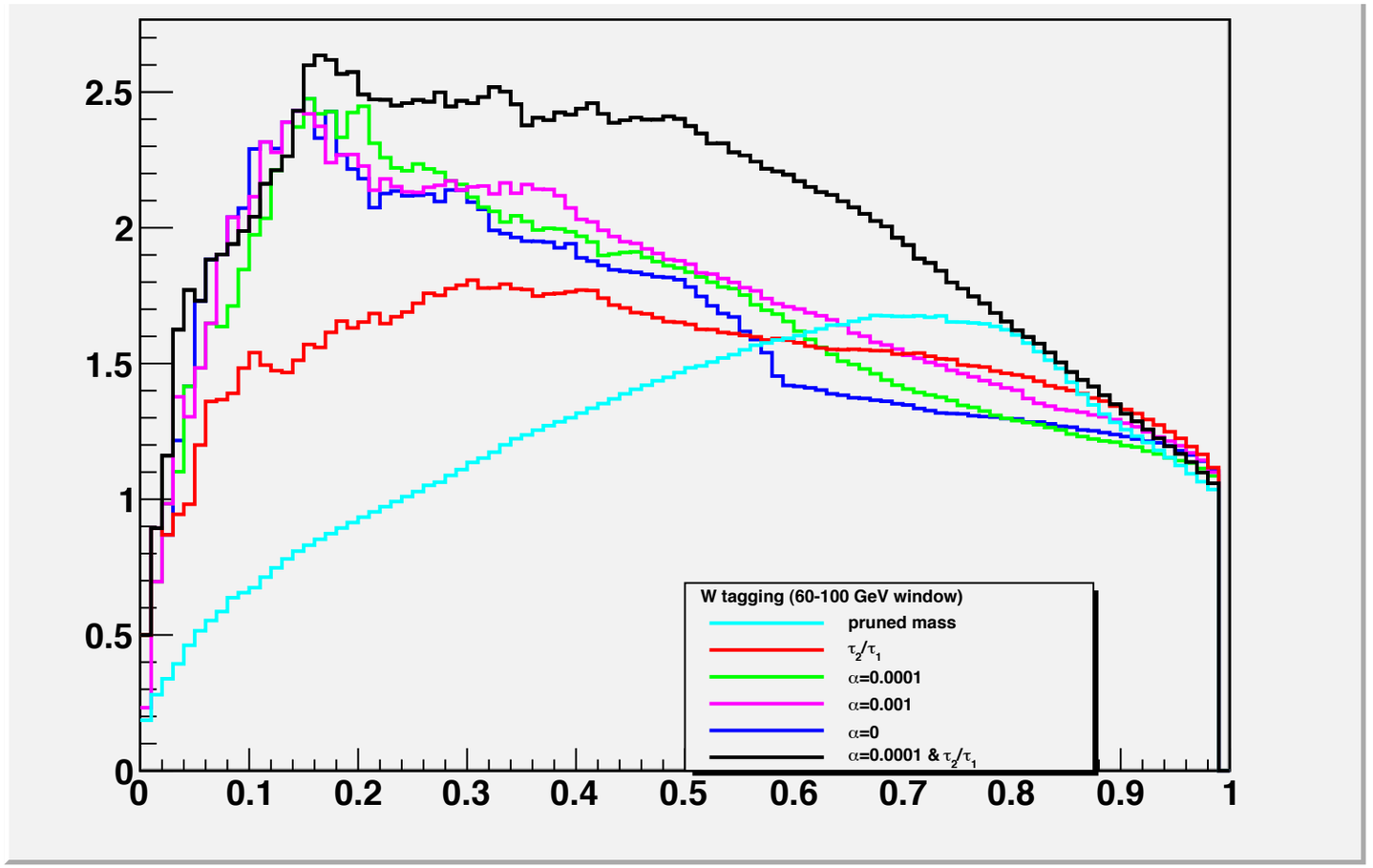




Application 1: discovery of W

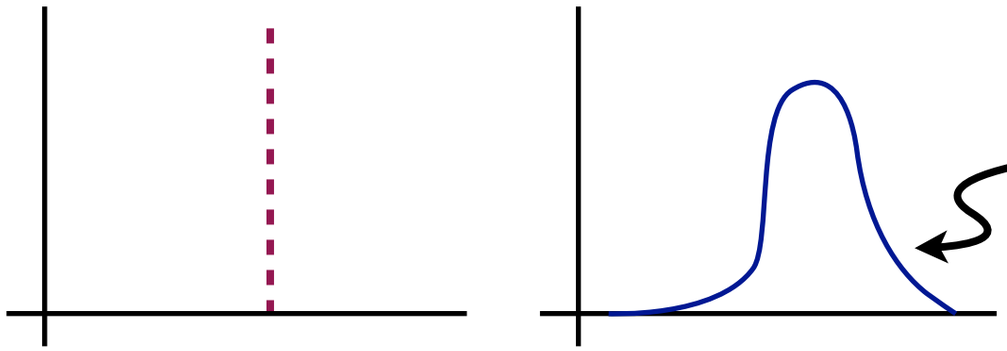
a cut on $\mathcal{V}$ decreases background significantly

Unofficial comparisons



QPruning vs. Pruning

Let us take a sample jet



How can this distribution be used?

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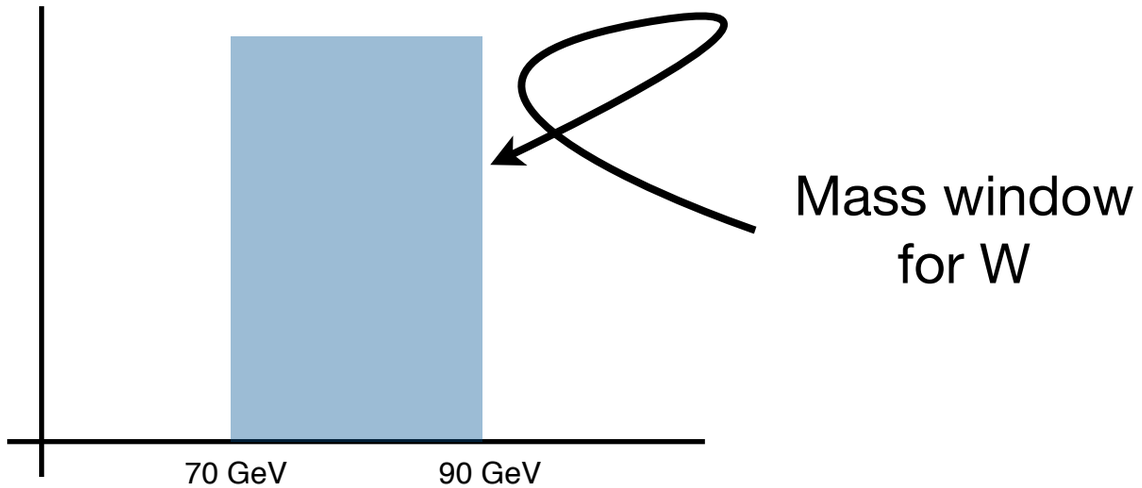
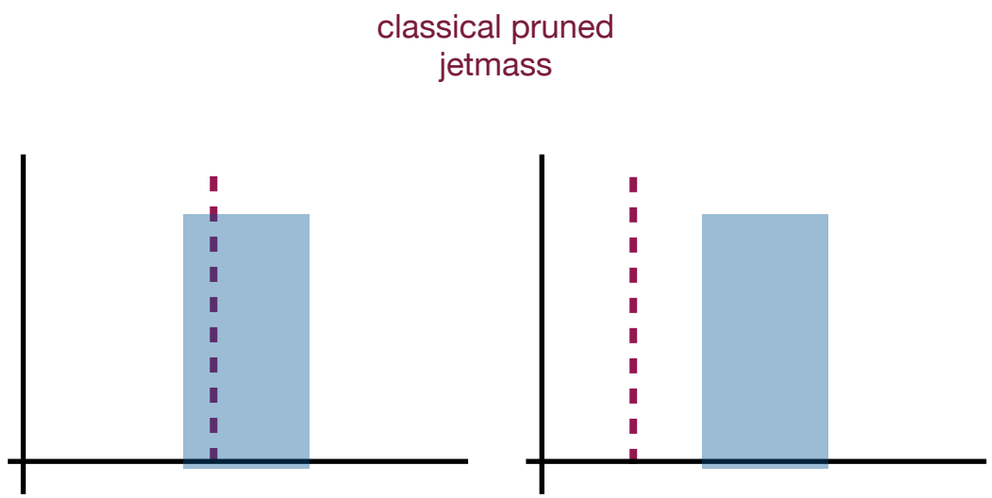
Application in determination of cross-section, mass etc.

QPruning vs. Pruning

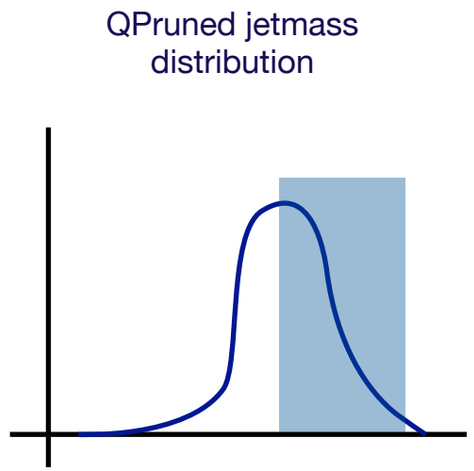
Consider candidates for a W jet





pruned mass is
either in or out of the bin

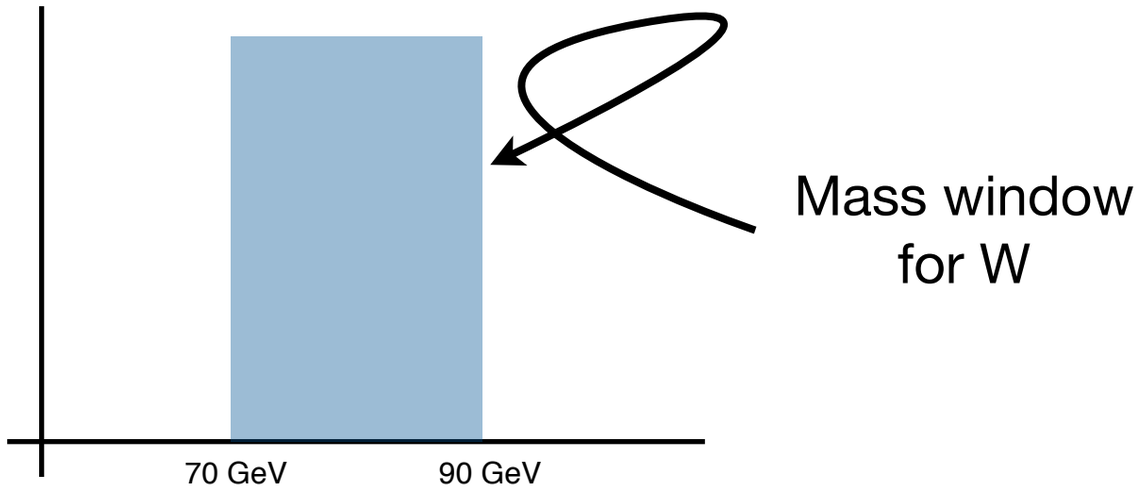
tagging efficiency is either 0 or 1

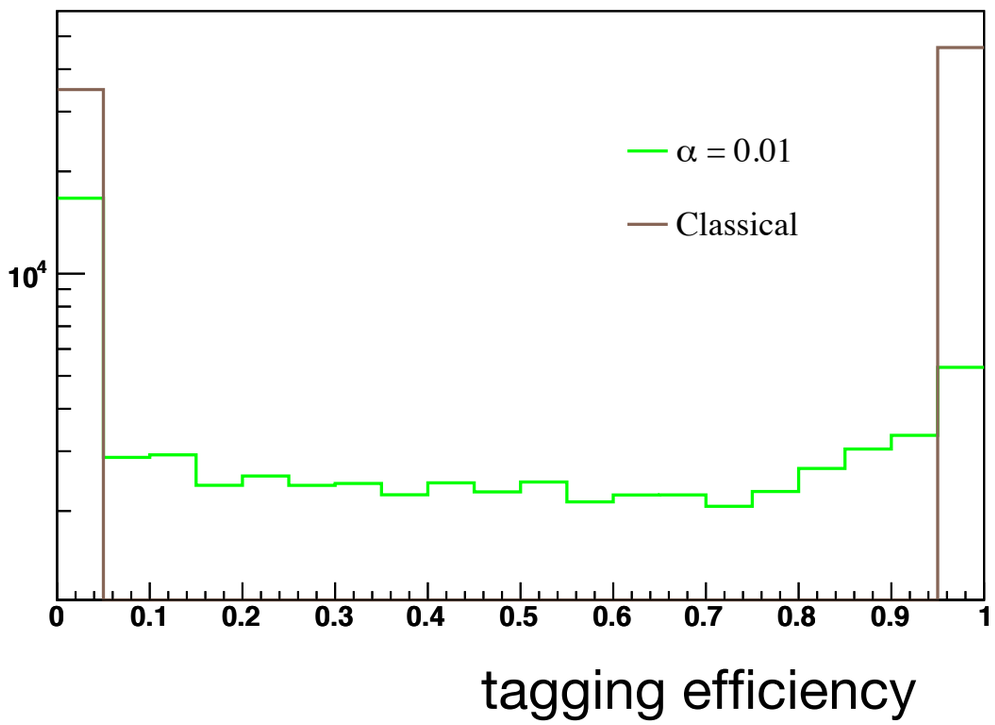


tagging efficiency is a number
between 0 to 1

QPruning vs. Pruning

Consider candidates for a W jet





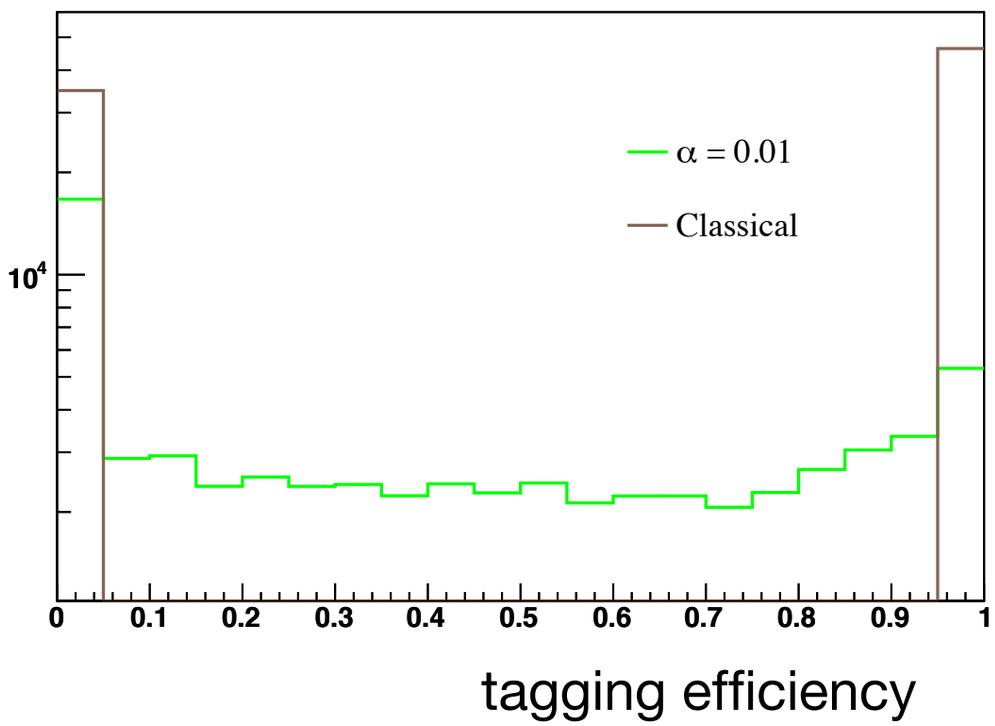
Pruning -> QPruning

A transition from a discrete (binomial distribution) to a continuous distribution

QPruning vs. Pruning

Pruning --> QPruning

A binomial distribution --> a continuous distribution



Use the distribution to reduce statistical fluctuations in measurements

QPruning vs. Pruning

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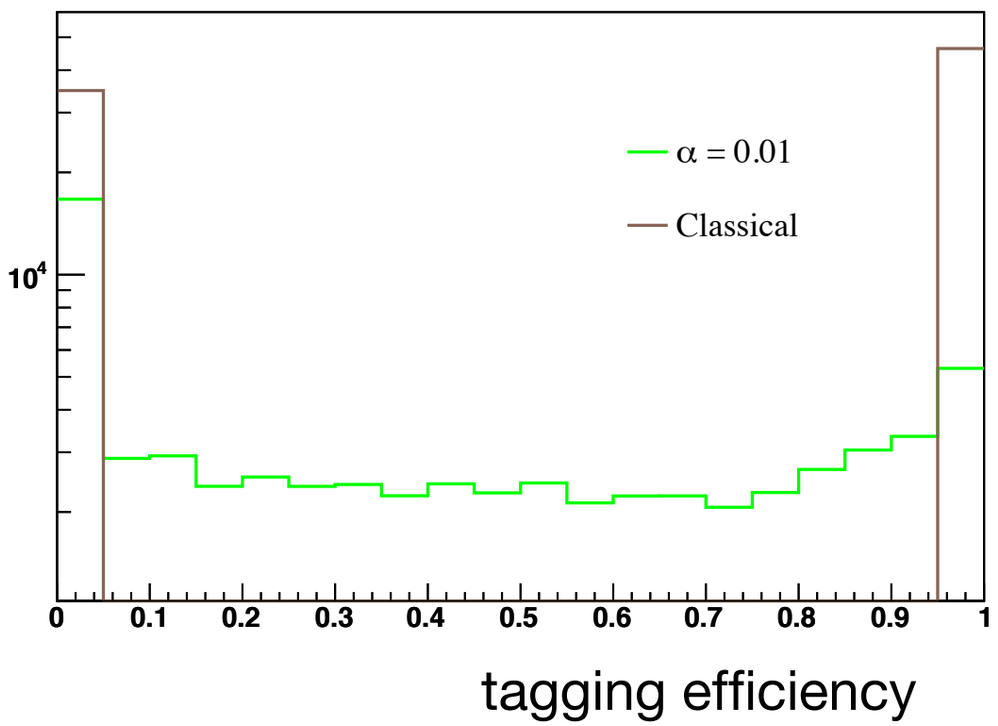


Use the distribution to reduce statistical fluctuations in measurements

How to measure statistical fluctuations ?

Statistical Fluctuation

Consider a large number of pseudo-experiments

# of jets in these pseudo-experiments vary according to Poisson distribution

Experiments	Measurements (e.g. # tagged jet)	
Expt #1	N_1	measure δN
Expt #2	N_2	
Expt #3	N_3	
Expt #4	N_4	
.	.	
.	.	
.	.	
.	.	
.	.	

Application 2: CS measurement

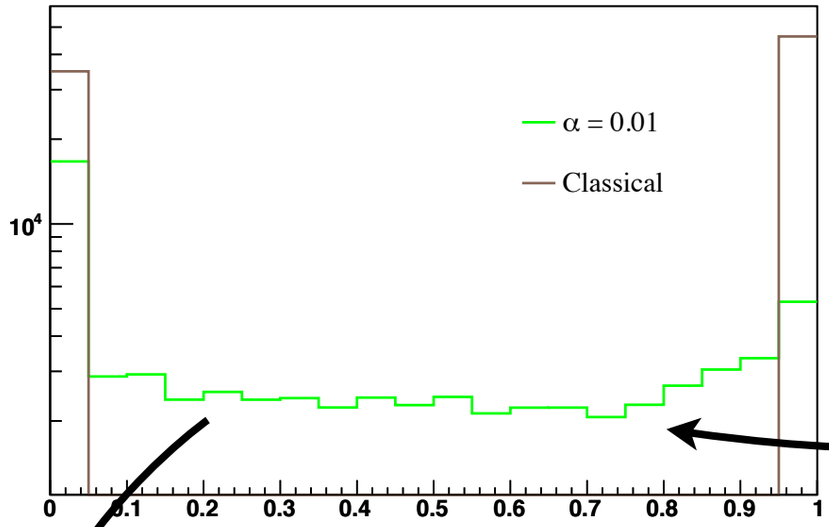
- As an example, take a sample of ~10 boosted QCD jets and ask for number of jets in a mass bin.

- The uncertainty associated with cross-section measurement decreases from classical pruning to QPruning

- Need half the luminosity to make a measurement of the same precision.

Algorithm	$\frac{\delta N}{\sqrt{N}}$	Relative luminosity required
prune with C/A	~1.0	1.0
QPrune	0.72	0.52

Application 2: CS measurement

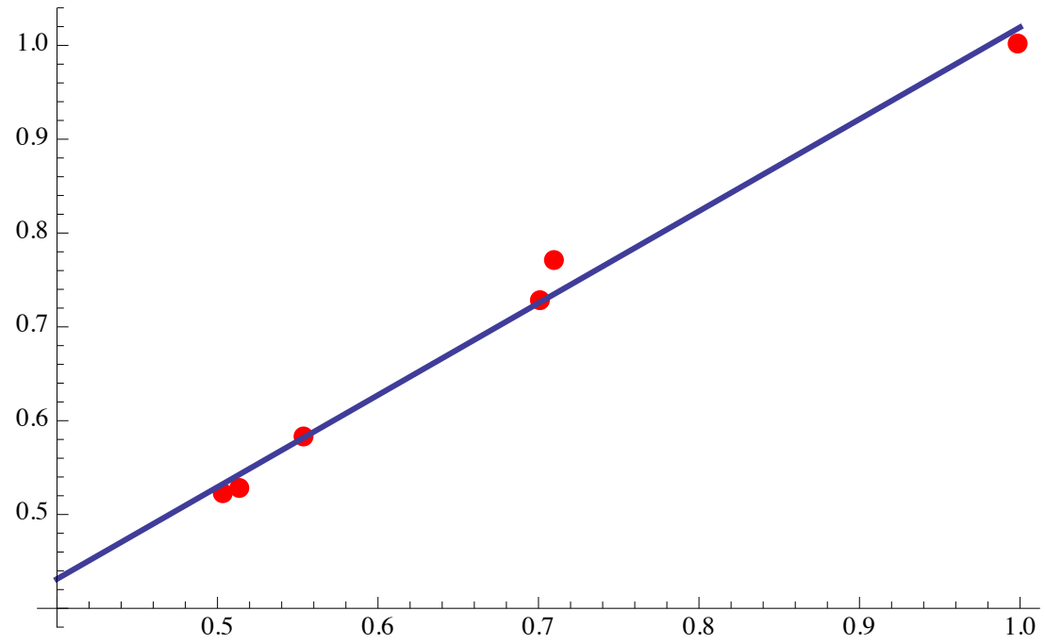


tagging efficiency

μ = average of the distribution

σ = standard deviation of the distribution

$$\left(\frac{\delta N}{\sqrt{N}}\right)^2$$



$$\mu + \frac{\sigma^2}{\mu}$$

Distribution completely determines the improvement in statistical fluctuation

Application 3: mass measurement

- As an example, take a sample of ~10 boosted W jets and ask for average jet mass.

- The uncertainty associated with mass measurement decreases from classical pruning to QPruning

- Need less than half the luminosity to make a measurement of the same precision.

Algorithm	Mass uncertainty [GeV]	Relative luminosity required
prune with C/A	3.2	1.0
QPrune	2.4	0.58

Future Directions

- In substructure physics, it still remains to be seen whether QClustering can be applied to other quantities such as mass-drop, Y_{23} etc.

- QClustering has been done on the elements of a jet. We intend to extend it to an entire event.

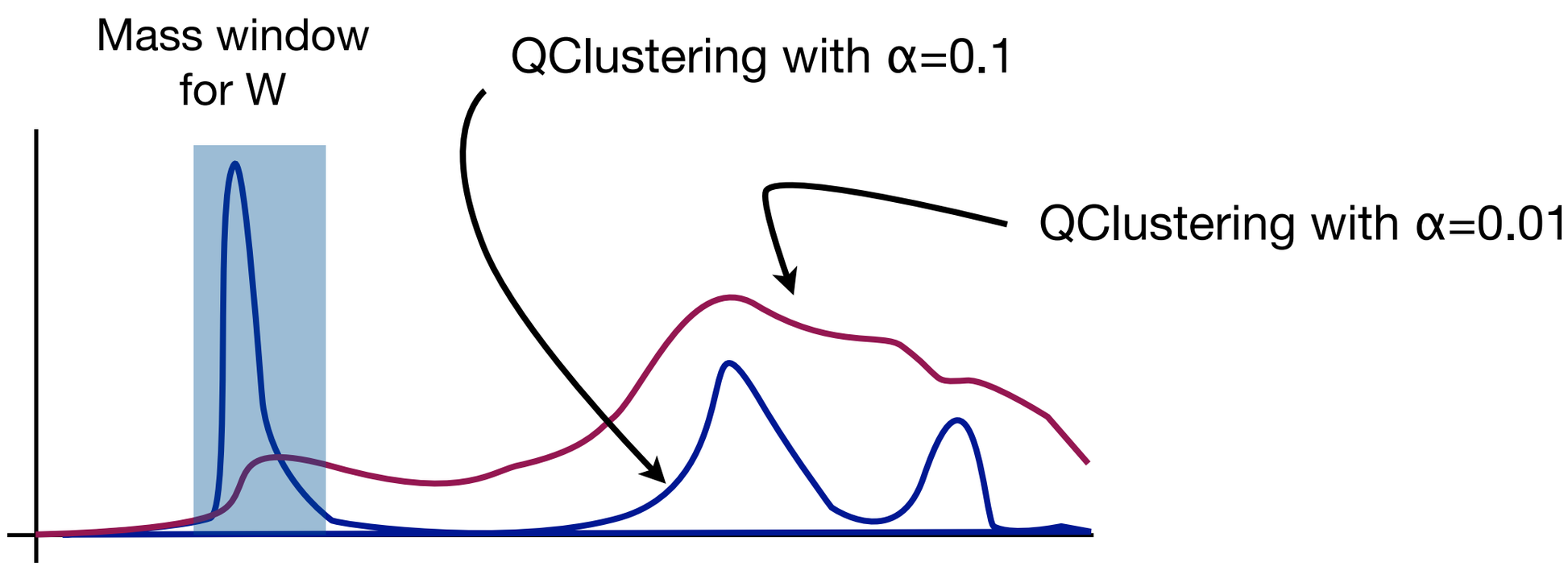
- We need to find a formalism towards analytical calculations.

Works in progress

- QClustering has been done on the elements of a jet. We intend to extend it to an entire event.

work in progress with Ellis
also Kahawala, Krohn, Schwartz

Q-Anti-k_T Clustering



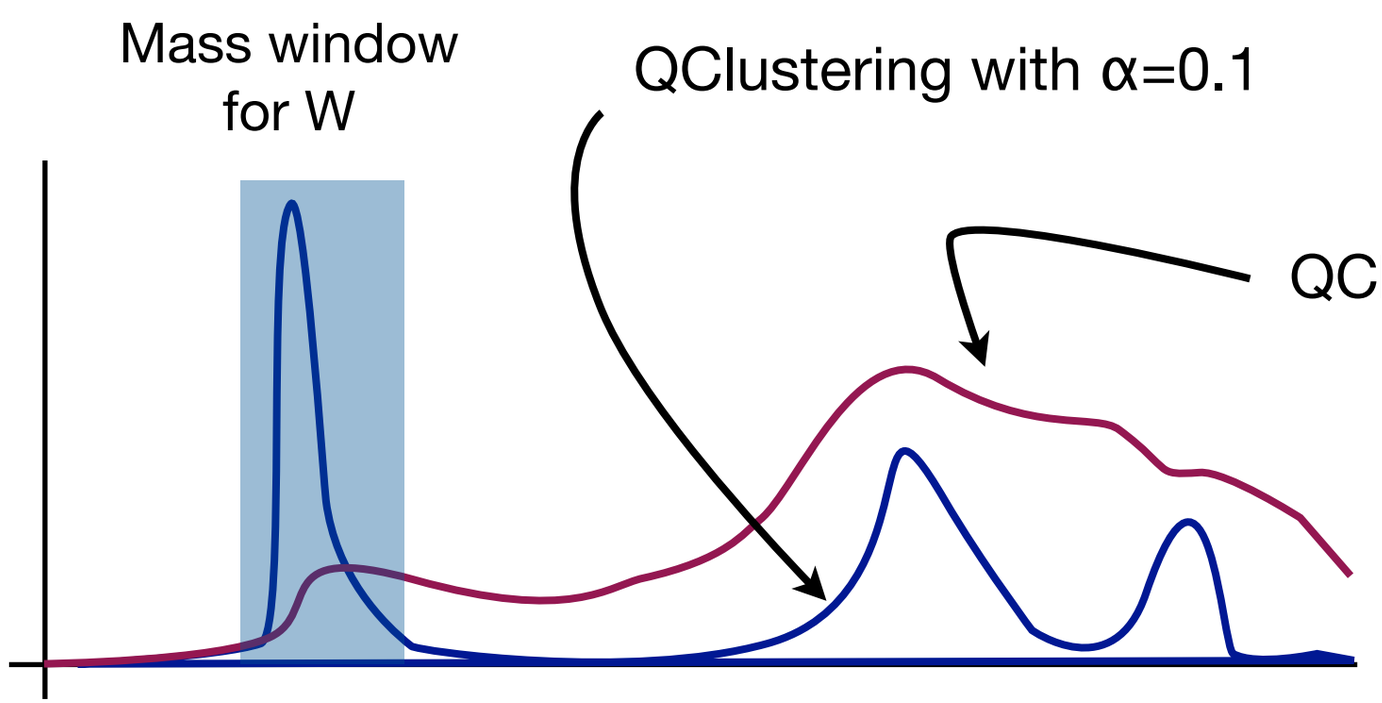
all di-jet masses in a W+jet event

Works in progress

- QClustering has been done on the elements of a jet. We intend to extend it to an entire event.

work in progress with Ellis
also Kahawala, Krohn, Schwartz

Q-Anti-k_T Clustering

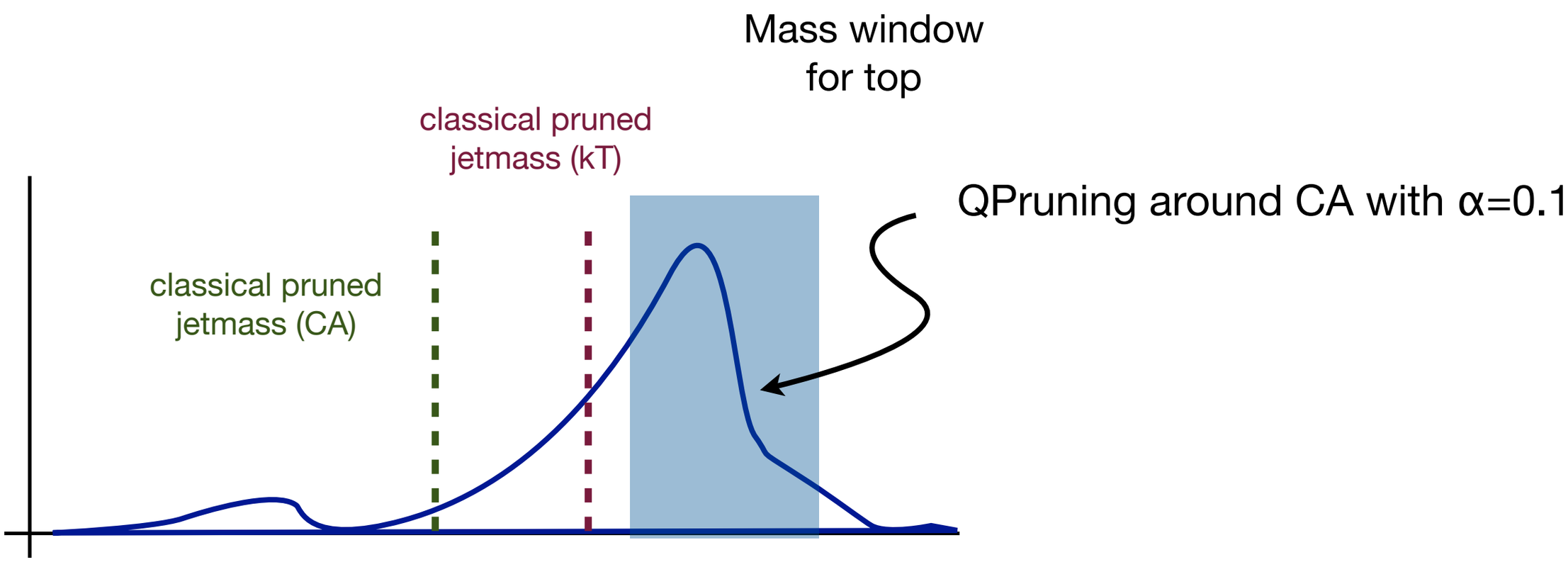


helps in suppressing
combinatorial background

all di-jet masses in a W+ 2jet events

Works in progress

- QPruning extended to an event (tt event)



Pruned jetmass for a top candidate (3-jet resonance)

Works in progress

- Towards analytically calculation for Qclustering

(Hornig & Schwartz)